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REFLEX WATERJET DESIGN STUDY
FOR APPLICATION TO THE AAAV
HIGH WATER SPEED AMPHIBIAN

FINAL TECHNICAL REPORT
APRIL 26, 1991

by

Waldo E.Rodler

Prepared Under Contract Number N00167-90-C-0058

for

MARINE CORPS PROGRAM OFFICE
DAVID TAYLOR RESEARCH CENTER
BETHESDA, MD

High Performance Marine Products
4811 Trailwood Way
Springfield, MO 65804

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A novel alternative configuration for waterjets was optimized and evaluated for application to high speed amphibians, like the planned AAAV. The concept demonstrated good performance in two generations of prototypes and a production run of units about half the size required for this application. Optimization analysis was based on methods confirmed by tests of the earlier units. Results show jet will provide satisfactory performance. Limited data indicates improved system performance will be realized from elimination of forward intakes of conventional waterjets. The optimization study showed a 16 inch waterjet to be optimum for the application. Adequate design engineering was performed to assure feasibility of the proposed design and availability of the needed components. The waterjet compares favorably to conventional designs in length, weight, maintainability, affordability and program risk. Installation studies show four jets can be installed on the proposed transom

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FOR   APPLICATION TO THE AAAV
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Final Technical Report
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MARINE CORPS PROGRAM OFFICE
DAVID TAYLOR RESEARCH CENTER
BETHESDA, MD

by: *Waldo E. Rodler*
Waldo E. Rodler

Approved: *R. Kent Wooldridge*
R. Kent Wooldridge

ABSTRACT

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INTEGRAL ELECTRIC MOTOR & REFLEX WATERJET
FOR HIGH SPEED AMPHIBIANS

1.   INTRODUCTION

Studies made for the LVA program indicated that higher water speed, on the order of 25 miles per hour, was needed for assault amphibians. This water speed would permit launching the amphibians so far from shore that the threat of land based missiles would be greatly reduced. The Falkland Island experience confirmed the validity of the requirement for increased speed.

The general size and configuration of an assault amphibian are driven by the military mission and the need to maintain a track contact length to tread ratio under about 2.8 to 1 to assure acceptable steering characteristics. The heavy weight (over 60,000 pounds) and small bottom area (about 250 square feet plus auxiliary systems) requires an unusually high lift coefficient. The size of the auxiliary systems like bow flaps, chine flaps and transom flaps is limited by practical constraints of land mode combat operation. The trim angles required to develop the required lift coefficients produce a high drag coefficient. The product of the high drag coefficient and the heavy weight produces a very large drag value that necessitates very high thrust. The size of affordable and proven engines is limited, therefor the required thrust must be achieved by a superior propulsive coefficient. The critical factor for a waterjet to achieve the required propulsive coefficient at low speeds is a high mass flow. This required high mass flow can only be provided by a large waterjet.

Studies of the AAAV with a conventional waterjet of the needed size showed that when the transom flap was retracted for land mode, the waterjets would protrude more than 20 inches above the rear deck. This protrusion interferes with rearward vision and gun depression. The folded flow path of the reflex waterjet merited study because it offered an opportunity to provide a much shorter jet that would not protrude above the rear deck of the AAAV.

This study optimized and evaluated an integral electric motor/waterjet design based on a unique waterjet configuration that has demonstrated improved performance compared to conventional waterjet arrangements in pleasure boat sizes. The aim of the effort was to develop a waterjet concept that would offer improved performance and/or reduced power requirement, reduced system weight, reduced material cost, conservation of strategic material and easier maintenance and repair. The prior experience with the similar concept for recreational boats provided confidence that these challenging goals could be reached.

Use of data from the design and test of previous recreational units of this general configuration minimized risk by constraining the study to proven range of design factors. Use of existing proprietary programs for hydrodynamic optimization and impeller configuration permitted a very detailed study to be made within the time and cost limitations of a Phase I SBIR program. The accuracy of these computer programs has been confirmed by extensive tests of waterjets built from the results of these programs. This detailed study assures that the configurations illustrated are feasible and provides a sound basis for the mechanical design and space requirements. The mechanical configuration is based on successful experience. The individual components are of simple, conventional design to minimize risk.

The scope of the study effort has been sufficient to provide the basis for a prototype. The hydrodynamics have been pursued in depth. The mechanical concept is based on previous successful units and has been reviewed for producibility and maintainability. Coordination with motor vendors provided assurance that multiple sources are available for the required motor.

2. DISCUSSION

2.1 DETAILED DESCRIPTION OF TECHNICAL WORK

2.1.1 PROCEDURES

2.1.1.1 PERFORMANCE OPTIMIZATION

The performance optimization was made by use of W. E. Rodler's proprietary program JETOPT9D. This program has been developed over a period of 18 years. The accuracy of the results produced by this program has been confirmed by tests of waterjets designed by its use and by comparison with the results of waterjet analysis by organizations like Aerojet, Rocketdyne, Dowty and Byron Jackson. Tests have shown performance variation of production waterjets built to the same design to be as much as +/- 2%. The results of this program have been found to fall within that scatter band.

The program starts with the basic physics of force equals mass times acceleration of the fluid. Corrections are then made for:

1. Inlet drag based on capture area, hull velocity and an experimental coefficient.

2. Ram head recovery based on velocity and an experimental coefficient.

3. Inlet flow loss based on curvature and convergence of the inlet.

4. Impeller efficiency based on tip velocity, diameter, cavitation limits, flow, and head.

5. Stator and nozzle losses based on geometry and experimental coefficients.

6. Unit size, flow velocities and anticipated surface finishes.

The program iterates through a very large number of combinations of these interrelated factors to achieve an optimized system result.

2.1.1.2 IMPELLER DESIGN

The impeller blade design program is based on an unpublished design method developed by Heinrich Schneider, the inventor of the automotive hydrodynamic torque converter. The toroid flow path essential to the basic torque converter mechanical design was not well suited to conventional blade design techniques, therefor this alternative method was established. The method was adapted to water pumps using information published by A. J. Stepanoff with additional modifications from Fuji Motors Corporation test data. The method has been developed into a proprietary program by W. E. Rodler and has been used to optimize the impeller design. Some of the advantages of blade systems designed by this method are:

A. <u>High resistance to cavitation.</u> Torque converters with this type of blades will operate without cavitation at a charging pressure of 35 psi compared to the 60 psi normal required by conventional designs. In waterjets, simple impellers have provided satisfactory operation suction specific speeds over **30,000**.

B. <u>High efficiency.</u> In a torque converter, efficiency is critical because it is directly related to vehicle performance and fuel economy. This situation motivated the research to develop more efficient blade designs. When applied to waterjets, tests indicate an improvement of approximately 3% over conventional designs.

C. <u>Simple contours that favor economical fabrication.</u> The method relates blade contours and passage cross section. By a series of design iterations it is possible to achieve a combination of simple blade contours with flow passage cross sections that provide high "through flow ability".

2.1.1.3 INLET CAPTURE AREA DESIGN

The design of the inlet is based on extensive tests made during the development of a 7.34" diameter recreational waterjet. The critical goals for this section of the waterjet system are:

1. Good ram head recovery
2. Low drag coefficient
3. Freedom from ventilation
4. Protection from entrance of foreign items

During the development of the 7.34" waterjet inlet, several satisfactory designs evolved. There were significant variations in the ram head recovery, but all of the satisfactory designs produced comparable free running performance. It was concluded that high levels of ram recovery were associated with corresponding high levels of inlet drag. The basic laws of conservation of energy appear to be at work. Increased ram head increased flow and gross thrust, but the added drag resulted in no measurable gain in the speed of a free running hull.

The initial inlet design for the 7.34" waterjet experienced a ventilation problem. As the hull approached planing speed, a fraction of air entered the inlet, and pump performance was seriously degraded. A minor modification of the inlet eliminated the ventilation problem and no problem was experienced with subsequent designs.

Operation with several variations of inlet grill was compared to operation without a grill. The effect of the well designed grills was found to be negligible. The most significant difference between the grill designs was found in their ability to shed rather than retain foreign items. None was found to be completely able to shed foreign items. The velocity and resulting impact forces are high. In one case a 12" length of a fir 2 by 4 impaled itself on a grill. The grill bar cut into the 2 by 4 as an axe might do, and significant force was required to dislodge this foreign item. The test program showed that an inlet grill was very desirable and that with proper design there was no measurable degradation of performance.

2.1.1.4   INLET ELBOW DESIGN

The inlet elbow design is based on the proven principles used in the design of the earlier reflex waterjets. The velocities and radii are retained. The low mounting position of the waterjet on the AAAV increases the net positive head, providing an additional margin of safety. The passageway is convergent to minimize losses and to provide improved velocity distribution at the impeller inlet (see appendix A, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, page 17).

The velocity of the water increases progressively through the entire waterjet. The waterjet is a system with a purpose of accelerating water to a high velocity at the nozzle. Torque converter design principles and experience with prior reflex waterjets indicate that highest systems efficiency is achieved with a "system approach" to flow velocity that provides the highest rates of acceleration after the impeller, where the head is the highest. Prior reflex waterjet designs have provided very high efficiency by using a constant jerk (rate of change of acceleration) from inlet to the nozzles. The velocity rates

through the inlet elbow are governed by this system principle. (see appendix B, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, page 18)

2.1.1.5 NOZZLE DESIGN

The inlets to the nozzle passages are aligned with the absolute direction of the impeller discharge flow. The stator of a conventional pump is eliminated as well as the stators losses and cavitation problems. Instead of "straightening out" the rotation of the impeller discharge flow, there is a smooth continuation of the angular acceleration started in the impeller. The passages continue the convergence to continue the progressive acceleration of the fluid. The nozzle size is determined by the area required to produce the discharge velocity determine by the performance optimization studies.

2.1.2 EQUIPMENT

2.1.2.1 COMPUTATIONS

Most of the optimization and design calculations were made by use of a Panasonic (IBM PC compatible) computer. The author made use of an extensive software library previously developed for converter and waterjet analysis to maximize the amount of analysis possible within the cost constraints of the program.

2.1.2.2 DRAWINGS

Drawings were made using conventional drafting equipment.

2.1.3 FACILITIES

No special facilities were required to perform this effort.

2.1.4 DATA

Extensive use was made of an unpublished proprietary data base developed from prior torque converter and waterjet studies and development programs. Public domain data has been used as noted in references throughout this report.

2.1.5 MATH COMPUTATIONS (successful and unsuccessful)

Sample calculations and copies of significant computer runs are attached as appendix D.

2.1.6 RESULTS

This study program has produced a low risk waterjet concept that provides the required AAAV thrust and offers the following advantages when compared to conventional configurations:

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1. Reduced waterjet length
2. Reduced waterjet weight
3. Reduced cost
4. Simplified maintenance
5. Improved hull performance

2.1.6.1 REDUCED LENGTH

Three major factors contribute to the reduced length of the reflex, or folded, configuration. First, the intake capture area is located below the main body of the waterjet, rather than well ahead of it. Second, the nozzles are located along the side of the pump, rather than behind it. Finally, a relative large diameter and correspondingly shorter motor can be used because it is not in the main water flow path where a large diameter motor would limit passage area and mass flow.

2.1.6.2 REDUCED WEIGHT

A weight estimate of 551 pounds, includes motor and intake. The motor weight is based an estimate from Uniq Mobility. It is typical of estimates from two other motor sources. The weight of the balance of the jet is proportioned from actual scale weights of a similar, but smaller, waterjet. See Appendix B, Mid Program Review, January 29, 1991, Page 16 for details of the calculation.

This weight is comparable to prior AAAV waterjets, but it is based on conventional aluminum construction. Application of composites, as done in the earlier AAAV waterjet should produce additional weight savings. A cost vs. weight study for alternative materials is planned as part of a Phase 2 program.

Extensive test experience with similar designs have shown that an aluminum impeller of the planned configuration will provide satisfactory performance and life. For details, see Appendix B, Reflex Jet Mid Program Review, January 29, 1991, Page 15. The aluminum material will result in savings of both weight and cost.

A further effective weight reduction will be realized from the more compact configuration and resulting reduced internal volume of on board water.

2.1.6.3 REDUCED COST

The aluminum impeller will reduce both material and machining costs. Aluminum can also be used for much of the balance of the waterjet without exceeding present target weights.

The simple interface between the motor and the waterjet is suitable for motors from most sources. This offers a potential savings in both development and production procurement.

The design and development problems of the land propulsion motors are far more severe than the waterjet motors because the

waterjet maximum horsepower requirement occurs at maximum RPM. The maximum power of the land mode motors must be delivered at low speeds, therefor these motors must be capable of producing much higher torque. The high torques result in a larger motor and more severe motor control problems. Any motor and control sources that can meet the land mode requirements can easily meet the waterjet requirements. The adaptability of the reflex waterjet to motors from various sources permits electrical system source selection to be made on the basis of the best land mode motor and control concepts. Reduced cost and better system design integration should result from having the land propulsion and waterjet motors and controls designed and produced by a single source.

2.1.6.4   SIMPLIFIED MAINTENANCE

The critical impeller, reduction gearing and motor components form a single sealed module that can be easily replaced in the field. This component module can be serviced by higher echelon personnel who have the necessary equipment and facilities to perform the clean and precise maintenance that is required by such components.

2.1.6.5   IMPROVED HULL PERFORMANCE

The effect of the rearward location of the water inlet of the reflex waterjet appears to be a significant factor in the performance of the watercraft system. Verification of the effects of this rear intake location and their quantification are necessary factors in a proper evaluation of the application of this waterjet system in comparison to conventional designs. The currently available information suggests more study in this area would be valuable.

Experimental indications:

Outboard Marine Corporation has conducted a series of tests comparing a matched pair of Cobalt boats powered by 305 CID Chevrolet engines. One boat had an OMC inboard/outdrive mounted propeller and the other had a conventional Jacuzzi waterjet with a forward water intake. The boat with the forward intake required an additional 5 mph speed to achieve plane. This curve is reproduced in Appendix A, REFLEX JET, October 10, 1990, Page 20 of 22. A possible explanation is that the higher dynamic pressure provided by the additional 5 MPH speed compensates for the loss of lift coefficient caused by the forward intake. Analysis of these data by use of Dr. Daniel Savitsky's planing hull analysis indicates the coefficient of lift was 0.045 for the hull with an inlet opening for a conventional jet and 0.070 for the propeller boat with no opening in the hull bottom. See the attached Appendix b, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 24 for the details of the analysis.

Free running tests of boats equipped with the reflex waterjet have consistently shown better performance than can be explained just by the performance of the waterjet itself. A Sea Ray SRV-

19, a Glastron V-174, and a Sportline 16 were all tested with Mercruiser Inboard/Outdrive propeller installations that were replaced and retested with reflex waterjets. Only the drive was changed. In all cases, the top speed of the jet was 1 to 2 MPH less than the propeller drives, but the acceleration times to achieve plane were reduced about 30 percent. Conventional jets typically require a 50 % more power to equal propeller performance. The reflex jet achieved fuel consumption rates comparable to the propeller installation. Conventional jets in the recreation boat industry are noted for their high fuel consumption.

Analytical considerations:

Analysis indicates that placing the waterjet inlet in the bottom of a hull should be undesirable and that the significance should increase with low hull speeds and high mass flow waterjets.

To achieve the desired performance, the waterjets of the AAAV will have a mass flow of about 20,000 gallons per minute each, or a total flow of 80,000 GPM, or 178 cubic feet per second.

Studies and tests have shown the AAAV hump speed will approach 18 miles per hour, or 26.4 feet per second. The cross section of the stream of water under the hull that will be diverted into the waterjet will therefore be 6.74 square feet. If the hull bottom between the tracks is about 7 feet wide, nearly one foot depth of water in this area will be diverted into the waterjets. This quantity should be enough to have significant effect on hull trim, lift and drag.

Tests have shown that a transom flap has a powerful effect on hulls like the AAAV. A transom flap with a 6 foot span and a 4 foot length would need to be set at a 16.3 degree deflection to present the same 6.74 square foot frontal projected area as the stream of water entering the waterjets.

Dan Savitsky and Peter Brown have published "Procedures For Hydrodynamic Evaluation of Planing Hulls In Smooth and Rough Waters" (Marine Technology, October 1976). Page 384 of this publication gives the following equation (5) for calculating flap lift:

$$f = 0.046 * Lf * \delta * \sigma * b * (p/2 * V^2)$$

Where: Estimate for AAAV

   f = Flap lift increment, pounds

   Lf = Flap chord, ft.   4

   σ = Flap span-beam ratio   6/11 = 0.5455

   δ = Flap deflection, degrees   16.3°

   b = Beam of planing surface, ft.   11

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p =   Mass density, slugs/cu. ft.   2

            V =   Speed, fps   26.4

Inserting values into the equation yields:

            f = 0.046 * 4 * 16.3 * 0.5455 * 11 * (2/2 * 26.4^2)

            f = 12,543 pounds

Since the mass of water diverted into the waterjets approximates
the water deflected by the above transom flap, the resulting
forces may be similar.

Independent comments:

Art Carlson, Designer of Glastron's "Carlson" line of high
performance boats:

        When shown the concept, he was the first person to point
        out the probable advantage of avoiding the waterjet inlet
        in the bottom of the hull.

Quoting a letter based on engineering analysis from W. H. Knuth,
Program Manager, Midrange Waterjets, Marine Systems, Aerojet
Liquid Rocket Company:

        "The aft-mounted intake would appear to benefit from the
        up-welling flow as it escapes from astern the transom to
        become the wake.

        All things considered, we should expect to see a boat that
        maintains a more level attitude traversing hump, achieves
        and holds plane at lower speeds, has less inlet related
        losses and therefore, improved thrust efficiency, reduced
        tendency to cavitate at startout, giving better
        acceleration and possibly reduced tendency to broach the
        inlet in a turn.

        A variety of mechanical design advantages come to mind as
        well which need not be listed here. I do believe the aft
        location of the intake offers potential for being shown to
        be superior to a through-hull intake in many if not all
        cases."

Quoting from a test report by David Moseley, Chief Engineer,
Propulsion Systems, Glastron Boats:

        "The pulling power of the package was demonstrated by
        towing a 180 pound slalom skier with three people in the
        boat. The boat pulled the skier up with no trouble at all,
        much easier than a CV-16 with a Merc 140.

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In general, the Sternjet unit was a very impressive prototype."

Notes by W. E. R.:

1. The CV-16 is a very similar Glastron boat.
2. The Merc 140 is an inboard/outdrive propeller with the same engine as used with the waterjet.

Quoting a letter from Gunnar Frandsen, Sales Development Manager of Volvo Penta of America, Inc.:

"The demonstration of the Sternjet extended to the management of VOLVO PENTA of AMERICA by Mr. Mallon last summer gave an indication that the concept has satisfactory performance and offers acceptable maneuverability when compared to an inboard outboard drive, and it was most impressive compared to existing jet drives.

Recommendation:

More study and test is necessary to confirm the magnitude of the effect of forward intake of a conventional waterjet vs. rearward intake of a reflex waterjet. The above material indicates that some effect exists and that the effect may be significant. Further study appears justified as a system approach to reducing the AAAV power requirement.

2.1.6.6 MINIMIZING PROGRAM RISK

The program risk has been minimized by basing the design on a proven concept and by a careful design effort that has retained all major design factors in a range of prior experience.

The basic concept has demonstrated its performance capability by extensive tests and operation of:

A. A first series of three prototypes as shown in Appendix A, REFLEX JET, October 10, 1990, pages 2, 3 & 4.

B. A second series of three prototypes and 50 production units as shown in Appendix A, Reflex Jet, October 10, 1990, pages 5 through 14

Throughout the Phase 1 design effort, the basic engineering factors from the above designs have been retained to minimize risk. Water velocities, curvature of passages, impeller blade angles, tip velocities, cavitation factors, and convergence are typical of the values retained within ranges established by previous successful experience.

The level of risk is therefor considered to be very low.

3.   DOCUMENTATION

3.1 The following documentation is provided in support of this
     contract:

3.1.1 DRAWINGS AND ILLUSTRATIONS

A.   Cross Section of Series #1 Prototypes
      (See Appendix A, REFLEX JET, October 10, 1990, Page 3
      of 22)

B.   Cross Section of Series #2 Prototypes
      (See Appendix A, REFLEX JET, October 10, 1990, Page 5
      of 22)

C.   Cross Section of a Conventional Waterjet
      (See Appendix A, REFLEX JET, October 10, 1990, Page 11
      of 22)

D.   Torque Converter Cross Section
      (See Appendix A, REFLEX JET, October 10, 1990, Page 11
      of 22)

E.   Side View, HPM Engine and Series #3 Waterjet
      (See Appendix A, REFLEX JET, October 10, 1990, Page 15
      of 22)

F.   Rear View, HPM Engine and Series #3 Waterjet
      (See Appendix A, REFLEX JET, October 10, 1990, Page 16
      of 22)

G.   HPM Outboard Jet
      (See Appendix A, REFLEX JET, October 10, 1990, Page 16
      of 22)

H.   AAAV Electric Waterjet Concept
      (See Appendix A, REFLEX JET, October 10, 1990, Page 17
      of 22)

I.   AAAV Electric Waterjet Concept, Revised
      (See Appendix B, REFLEX JET MID PROGRAM REVIEW,
      January 29, 1991, Page 4)

J.   AAAV Impeller and Reduction Gear Cross Section
      (See Appendix B, REFLEX JET MID PROGRAM REVIEW,
      January 29, 1991, Page 5)

K   AAAV Reflex Waterjet Elevation and Rear View, 1/2
      Scale
      (CDRL item A001)

L.   AAAV Reflex Waterjet Cross Section, 1/2 Scale
      (CDRL item A001)

M.   AAAV Reflex Waterjet, Typical AAAV Installation
      (figure 1)   Page 19

N.   Trunnion Mount Steering System
      (figure 2)   Page 20

O.   Alternate "T" flap concept with walkway and crew door
      (figure 3)   Page 21

3.1.2   INTERMEDIATE REPORTS

The following intermediate reports have been supplied:

A.   Monthly progress reports for October, November and
      December of 1990 and for January, February And March
      of 1991.

B.   October 10, 1990 Kickoff Meeting presentation data
      attached herewith as appendix A.

C.   January 29, 1991 Reflex Jet Mid Program Review
      presentation data, attached herewith as Appendix B.

3.1.3   LABORATORY REPORTS

No laboratory reports were prepared or submitted as part of this
contract.

3.1.4   CONFERENCE REPORTS

No conference reports were prepared or submitted as part of this
contract.

3.1.5   OTHER RESEARCH SOURCES

None.

4.   STATUS OF ACCOMPLISHMENTS

4.1 ASSIGNMENTS

4.1.1   PERFORMANCE OPTIMIZATION

The optimization study started with a matrix of computer runs to
using W. E. Rodler's proprietary "JETOPT9" program. This program
has been developed over a period of eighteen years. Computer
results have been compared to test results to confirm the
effectiveness of the program. Comparisons of computed and test
values are show in Appendix A, REFLEX JET, October 10, 1990,
Page 14 of 20. Additional comparison have been made with
analytical results from Aerojet, Rocketdyne, Byron Jackson and
others to provide additional confidence in the accuracy of
program results. The results fall within the +/- 2% scatter band
that is typical for production waterjets.

The results of these are shown in Appendix B, REFLEX WATERJET
MID PROGRAM REVIEW, January 29, 1991, Pages 7 through 13. The

results of an optimum combination of these factors is shown on page 6 of the same Appendix B.

4.1.2 HYDRODYNAMIC DESIGN

The first step was to establish the normal velocity of the water flowing through the waterjet system. The velocity at the capture area of the inlet was established based on previous experience at 31 feet per second at the 18 MPH hull speed. This results in an inlet velocity ratio of 1.17, which has proven satisfactory in prior designs.

The nozzle size and discharge velocity was determined by the optimized computer run using the "JETOPT9" program. The nozzle area of 104.9 square inches resulted in a discharge velocity of 64.11 feet per second.

Between these two points, the flow velocity was determined by maintaining constant jerk (rate of change of acceleration). This velocity distribution produces convergent flow throughout the system.

The inlet duct design was derived from previous successful designs. Test of the previous units have shown a favorable velocity distribution at the impeller inlet using this design (see Appendix A, REFLEX JET, October 18, 1990, page 13 of 22).

The impeller is of a forced vortex design. This type of blade design has been extensively used in automotive torque converters. It produces a blade that has less difference between blade angles at the blade tips and roots than free vortex designs. The resulting blade shapes are stronger and easier to produce. The blade angle is also a function of the radius to each specific point on the blade. A series of impeller cross section modifications were made that retain the desired normal velocity distribution, but refine the blade angles to achieve simple, easily produced contours. The results of this optimization is shown in Appendix B, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 20.

The design of the stator and nozzle assembly, like the intake, follows the principles of previous successful designs. The rates of acceleration are higher, but the head is also much higher, which avoids the risk of cavitation.

4.1.3 MECHANICAL CONCEPT DESIGN

The general mechanical design follows previous successful designs. For this application the entire waterjet is supported by the intake elbow. This arrangement has been selected to assure that the transom flap deflections induced by the pressure variations from wave action are isolated from the pump and motor sections of the waterjet. This isolation minimizes the required impeller tip clearance, which improves pump efficiency and

extends the service life before excessive tip wear necessitates maintenance.

The motor is mounted to the waterjet by means of a mounting face, pilot ring and bolt circle. This arrangement has been extensively used in aircraft applications for mounting high speed (12,000 RPM) alternators and hydraulic pumps. The motor is easily removed for repair or replacement and the electrical terminals are readily accessible which simplifies installation and sealing of the electrical wiring. A key advantage to this arrangement is that it is adaptable to motors of various sources. While no "Off the shelf" motors have been found to meet the requirements of this application, four sources have been found who are able to produce motors for this requirement. (See Appendix B, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 22)

The impeller is driven from the motor by means of star gear reduction gearing. A star gear set is similar to a planetary gear set, but the carrier is stationary and the sun and ring gears rotate in opposite directions. A single stage of gearing provides the needed ratio to match the speed of the available motors to the impeller speed. The impeller is mounted to and extension of the stationary carrier by means of a pair of tapered roller bearings. The generous spacing between these bearings provides the rigidity necessary to minimize any possibility of rubbing between the impeller tips and the waterjet housing. An external spline on the ring gear drives the impeller and axial location of the ring gear is maintained by an internal snap ring. Gear loads, bearing sizes and seal rubbing velocity have been checked and suitable sources located for these components. Enough analytical work has been done to assure feasibility of the design, but an optimization effort is anticipated as part of phase 2 of the development. A cross section of these items is shown in Appendix B, REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 5.

4.1.4   JET SYSTEM CONCEPT

The reflex waterjet configuration offers significant advantages over conventional arrangements.

There is considerable flexibility in the installed dimensions of a given diameter reflex waterjet. Various combinations of nozzle locations, nozzle shapes and inlet horn widths permit significant variations to suit specific applications. The current configuration proposed for the AAAV is 52 inches long, 21 inches high and 21 inches wide. A typical alternative could have a wider, but shorter inlet elbow. This could offer a waterjet that was only 40 inches long, 21 inches high and 27 inches wide. A coordinated effort with the vehicle manufacturer as part of the Phase 2 effort would permit optimizing the waterjet configuration for the specific vehicle application.

The motor envelope is relatively flexible. The face mounting to the drive is a widely used in aircraft, machine tools and pumps.

The motor diameter can be as high as 18 inches without effecting the overall package dimensions of the motor-waterjet system. The motor length adds directly to the system length, but the short length of the reflex jet allows use of any motors of normal proportions without exceeding the 60 inch overall target length for the motor-waterjet system. This dimensional flexibility enables many sources to supply a suitable motor and provides the significant advantage of competitive procurement.

The manufacturing cost of the reflex jet compares favorably with more conventional designs. The compact configuration requires less material. The favorable velocity distribution at the impeller inlet avoids the need for the complex inducer type of impeller. The simple mixed flow impeller is much easier to produce. The motor is not exposed to pump output pressure, minimizing seal cost and potential failures of a high speed, high pressure seal. The difficult problem of providing and sealing passages to an internal motor for the electrical power supply is completely avoided. The modular construction of the motor/reduction gear/impeller assembly significantly facilitates both manufacturing and maintenance.

4.1.5   INTEGRATION WITH THE VEHICLE

The reflex waterjet can be mounted directly to the transom flap as shown in figure 1. As noted in section 4.1.4, there is a reasonable degree of flexibility in the proportions of the reflex waterjet. A Phase 2 study should include a coordinated effort with the vehicle manufacturers to achieve the best integration of the transom flap system with the waterjet.

The waterjets are required to provide the moments to steer and control the vehicles motion at the higher speeds when the maneuvering jets are ineffective. There are three potential ways to do this. It can be done by differential motor (and impeller) speeds, by individual nozzle jet deflectors or by swiveling a jet that is mounted on vertical trunnions.

The differential motor speeds is probably the best and lightest solution for the AAAV. It adds no mechanical components. The electronic controls for land mode operation have the variable speed capability that is necessary to provide this control for the waterjet motors. This is increased possibility of waterjet cavitation at low speeds when much of the total power might be delivered to only two of the jets, but at those speeds they primary steering control is from the maneuvering jets. The steering moment with this type of control is greatest with widely spaced jets.

The use of individual nozzle deflectors produces a complex mechanical design. It offers the advantage of redundant control systems in case of damage or failure. This system does not impose added requirements on the electric controls and does not increase the possibility of cavitation.

FINAL REPORT, April 26, 1991, Page 15

Jets mounted on a vertical trunnion as shown in figure 2 provide a relatively simple steering arrangement. Such steering has been used on prior reflex waterjets. It was found to provide very positive steering and the energy to control the system was very low. There would be a minor loss of effective transom flap area.

A further optimization of the AAAV transom flap might be achieved by use of a reflex style waterjet for the maneuvering jets. The general configuration of a reflex maneuvering jet would be similar to the HPM waterjet shown in Appendix A, REFLEX JET, October 10, 1990, Pages 15 & 16 of 22. For the maneuvering jet application, the nozzle assembly would be rotated 90 degrees to place the two discharge nozzles almost tangent to the hull sides. Steering and reverse would be achieved by means of the deflection plate and reverse port as illustrated. Improvement in the maneuvering jet performance would result from a less restricted inlet condition behind, rather than above the upper track chord and from the greater moment arm between the waterjet nozzles. The greatest advantage would result from the wider transom flap made possible by the greater distance between the discharge from the left and right maneuvering jets. This added width would permit a troop walkway between the jets as shown in figure 3.

5.   TESTS

5.1 No tests were conducted as a part of this program.

5.2 Extensive use was made of the data base developed from prior tests.

The first series of tests was made with the Series #1 prototypes illustrated in Appendix A, REFLEX JET, October 10, 1990, Pages 3 & 4 of 22. This series of jets were of a 195 mm (7.68 inch) diameter. Three prototypes were built. One was bench tested for static thrust and durability. The second was installed and tested in the illustrated Sidewinder hull. Tests included free running performance, pressures, flows, inlet losses and cavitation characteristics.

The second series of tests was made with the Series #2 prototypes illustrated in Appendix A, REFLEX JET, October 10, 1990, pages 5, 6, & 7 of 22. The three prototypes were installed in a Sea Ray 190, a Sportline 16 and a Glastron SRV174. The Sea Ray was tested for thrust, flow, losses, free running performance and durability. The Sportline was tested for thrust, flow, losses and free running performance. The Glastron was tested for free running performance and durability.

Approximately fifty production units of the Series #2 design were manufactured, sold and installed in various boats. Data was gathered from a few of these installations. Performance was generally comparable to propeller installations. Very few spare parts have been required to support these units.

The tested units were approximately one-half the size of the proposed waterjet for the AAAV. As such, the test data replaces much of the data that would be obtained from the half size prototype frequently incorporated in larger waterjet programs. Program risk is greatly reduced by this relevant experience and data. The would be a minimal gain from additional half size prototypes in the AAAV program, therefor proceeding directly to a full size prototype is recommended.

6. SUMMARY

6.1 MEETS GOALS

The Reflex Waterjet is an attractive alternative to conventional waterjets for the AAAV. The thrust performance can equal the best conventional waterjets. The rear water inlet location appears to have a beneficial effect on hull performance. The unit is very short. The noise signature should be low because of the simple impeller, high cavitation margin and no direct sound radiation paths from the impeller blade tips to the outside water. There are trade offs in length, width and height that can be used to optimize the reflex waterjet for specific applications. Weight goals are met with conventional materials and further weight reductions could be realized by use of alternative materials like composites for the intake elbow and silicon carbide aluminum for the impeller.

6.2 LOW TECHNICAL RISK

The data gathered from the extensive tests and experience with reflex jets about one half the size that would be needed for the AAAV greatly reduces program risk. Engineering tests, hundreds of hours of durability tests and practical experience with commercial users minimizes the technical risk associated with the development of the reflex jet for the AAAV application.

6.3 MAINTAINABLE

The modular construction of the motor, reduction gear and impeller assembly greatly facilitates maintenance. These main maintenance items are readily accessible for repair or replacement. Simple, conventional construction avoids the need for many special tools.

6.4 AFFORDABLE

Since the design goals can be met with conventional construction and materials, costs will be minimized. A further significant cost reduction can be anticipated from the potential to have multiple competitive sources for the motor. Tests have shown that an expensive inducer impeller is not required for the reflex jet, therefor a much less expensive mixed flow impeller will be used. Extensive experience with smaller similar units will minimize development cost. The costly fabrication and test of a half scale model appears unnecessary. The funding that might otherwise be used for the half scale model, could be

invested in a complete set of the non standard parts to support the test program. This ample supply of spares would minimize the risk of expensive delays during the test program.

7. CONCLUSION

7.1 The reflex jet is an attractive alternative for the AAAV water propulsion system.

The Reflex Jet meets the requirements for water propulsion of the AAAV in a compact, light weight package that combines low technical risk, easy maintainability and affordability. The unique configuration offers a potential system performance advantage by avoiding the losses associated with conventional waterjet inlet located in the primary hydrodynamic lifting area of the hull.

The use of reflex maneuvering jets in combination with the reflex propulsion jet offers an opportunity to use a wider transom flap that could incorporate a troop walkway between the waterjets. This arrangement would provide improved combat effectiveness by partially protecting troops from enemy fire and by speeding their entry and egress.

8. RECOMMENDATIONS

8.1 Proceed with a phase 2 program to build and test a prototype reflex waterjet.

Key factors of this program should include:

A.   Close coordination of the reflex water design with the transom flap assembly design and development to improve over water performance and combat effectiveness.

B.   Use of existing data base to avoid the need for half scale prototypes and tests.

C.   Obtaining a complete set of non standard spare parts to assure that the test program remains on schedule and budget.

AAAV REFLEX WATERJET, TYPICAL INSTALLATION
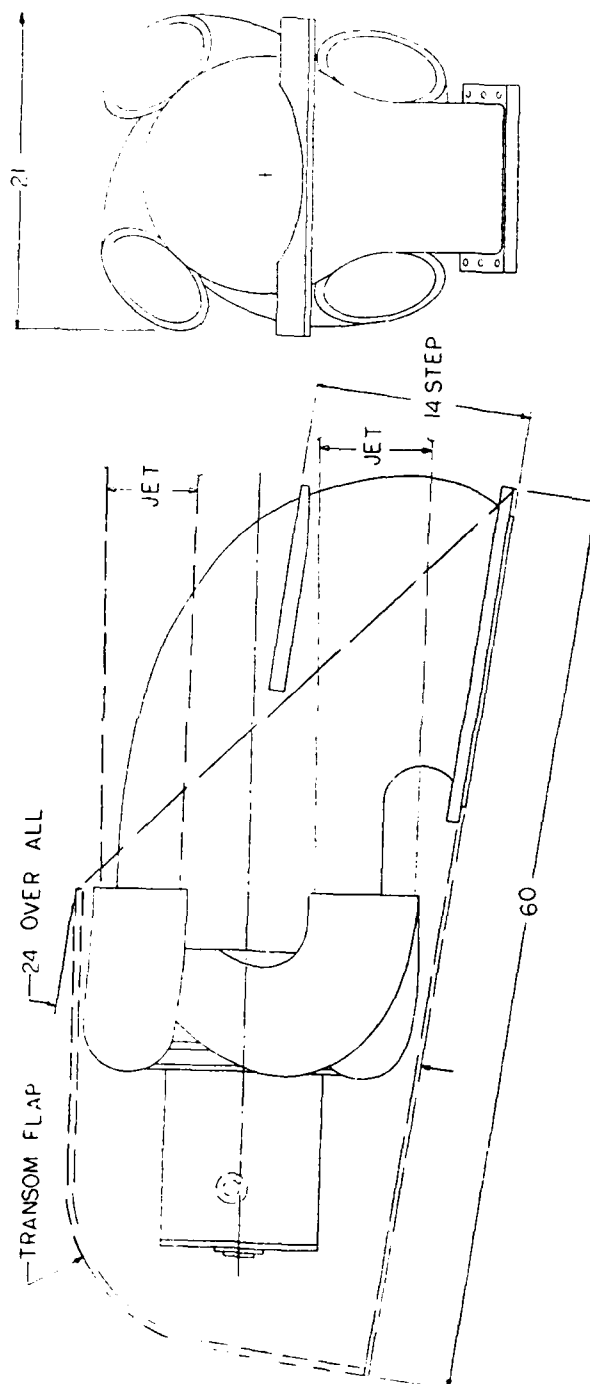
FIGURE 1

TRUNNION MOUNT STEERING SYSTEM

TRANSOM FLAP

24 OVER ALL

MOUNTING TRUNNION

JET

JET

60

FIGURE 2

REFLEX MANEUVER JET

JET

32 X46 DOOR

60

40

36 WALKWAY

132

DEPLOYED FLAP, PLAN VIEW
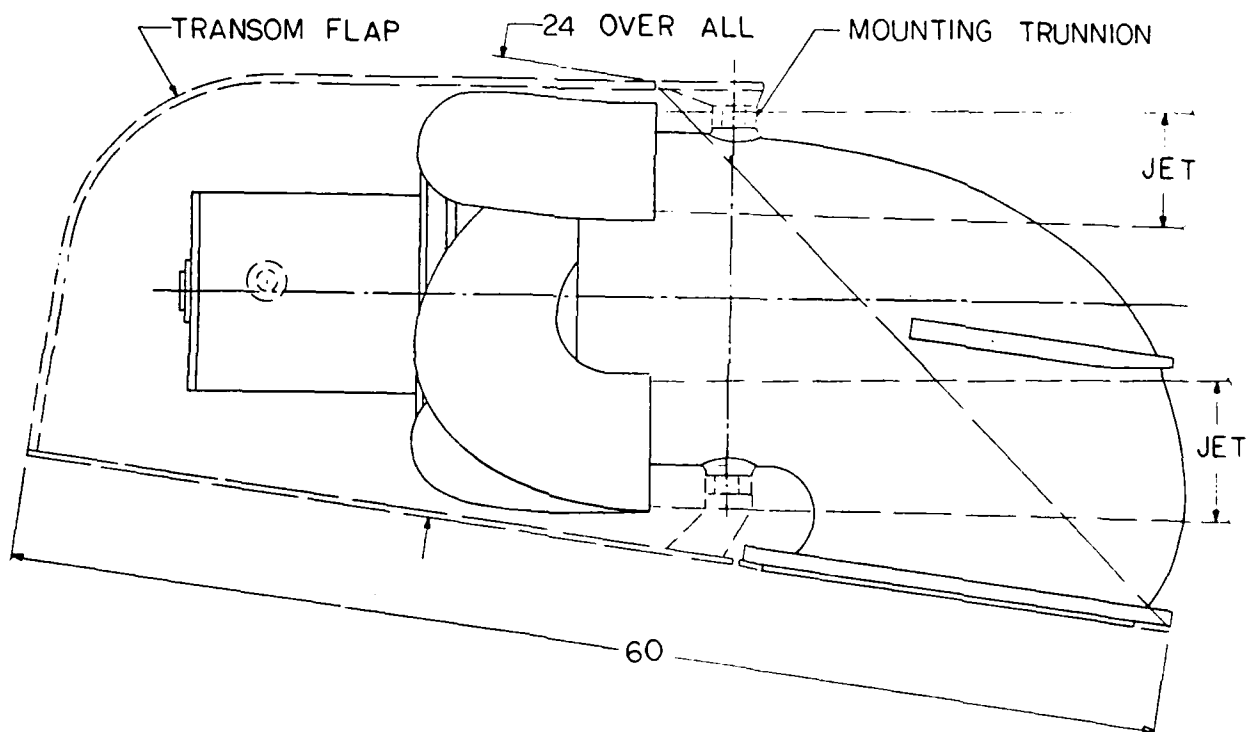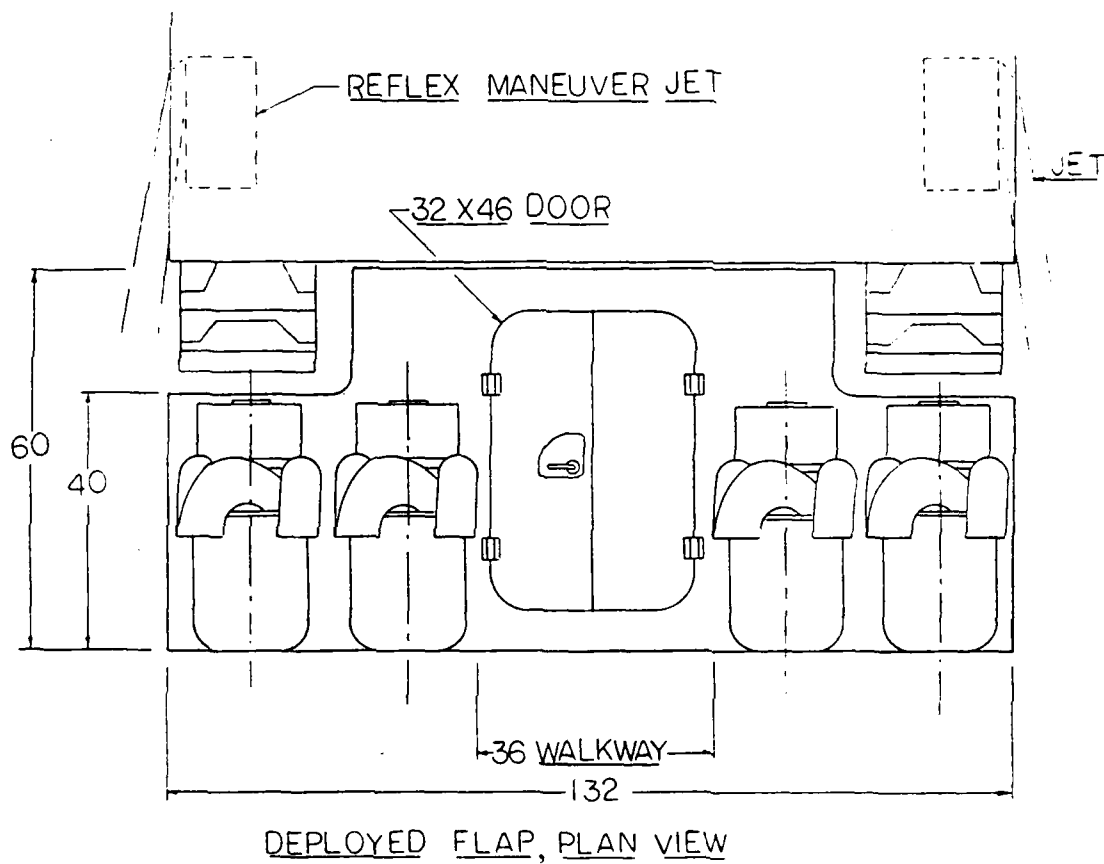
FIGURE 3

APPENDIX A

REFLEX JET TECHNICAL PRESENTATION

by

Waldo E. Rodler
1488 Cherry Garden Lane
San Jose, CA 95125

Presented at Kick Off Meeting
Springfield, MO

October 10, 1990

HIGH PERFORMANCE MARINE PRODUCTS

Springfield, MO

<u>**REFLEX JET TECHNICAL PRESENTATION**</u>

By: Waldo E. Rodler

October 10, 1990

KEY CONTRACT PERSONNEL:

BUSINESS MANAGER

R. Kent Wooldridge
4811 Trailwood Drive
Springfield, MO 65804
(417) 822-9218

PRINCIPAL INVESTIGATOR

Waldo E. Rodler
1488 Cherry Garden Lane
San Jose, CA 95125
(408) 264-5592, 416-5663

ORIGINAL CONCEPT COMBINED:

High Speed Steam Locomotive Water Pick Up

Torque Converter Stator

Torque Converter Pump Impeller

Annular Nozzle, Like Converter Flow Into Turbine

SERIES #1 PROTOTYPES:

CONSTRUCTION

Rear Intake
Annular Jet Discharge
Deflected Reverse
Swivel Steering

PERFORMANCE

Speed Equals Other Jets
Acceleration Equals Other Jets
Very Good Steering
Fair Reverse
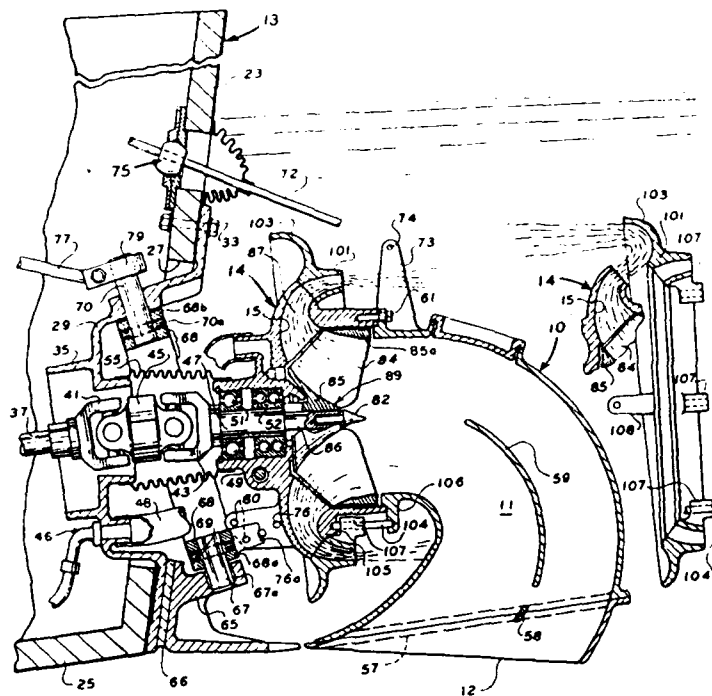
CROSS SECTION SERIES #1 PROTOTYPES
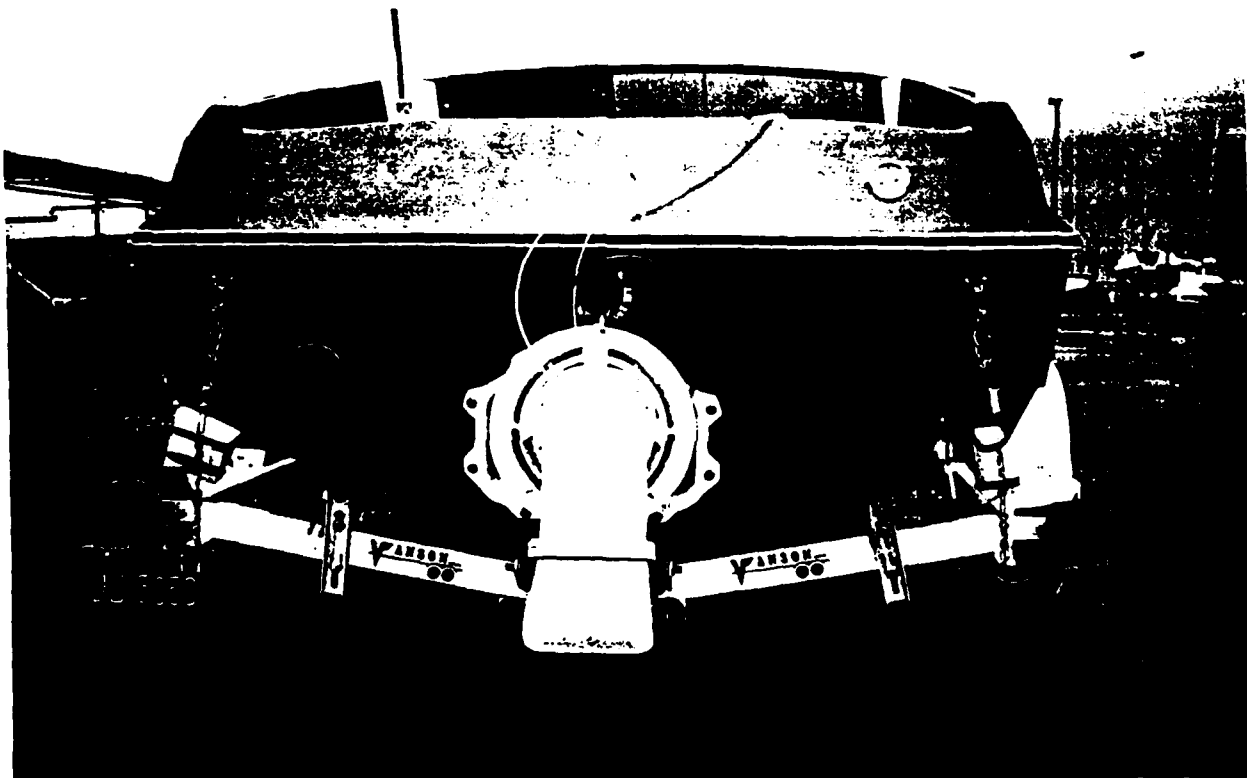
REAR VIEW, SERIES #1 PROTOTYPE
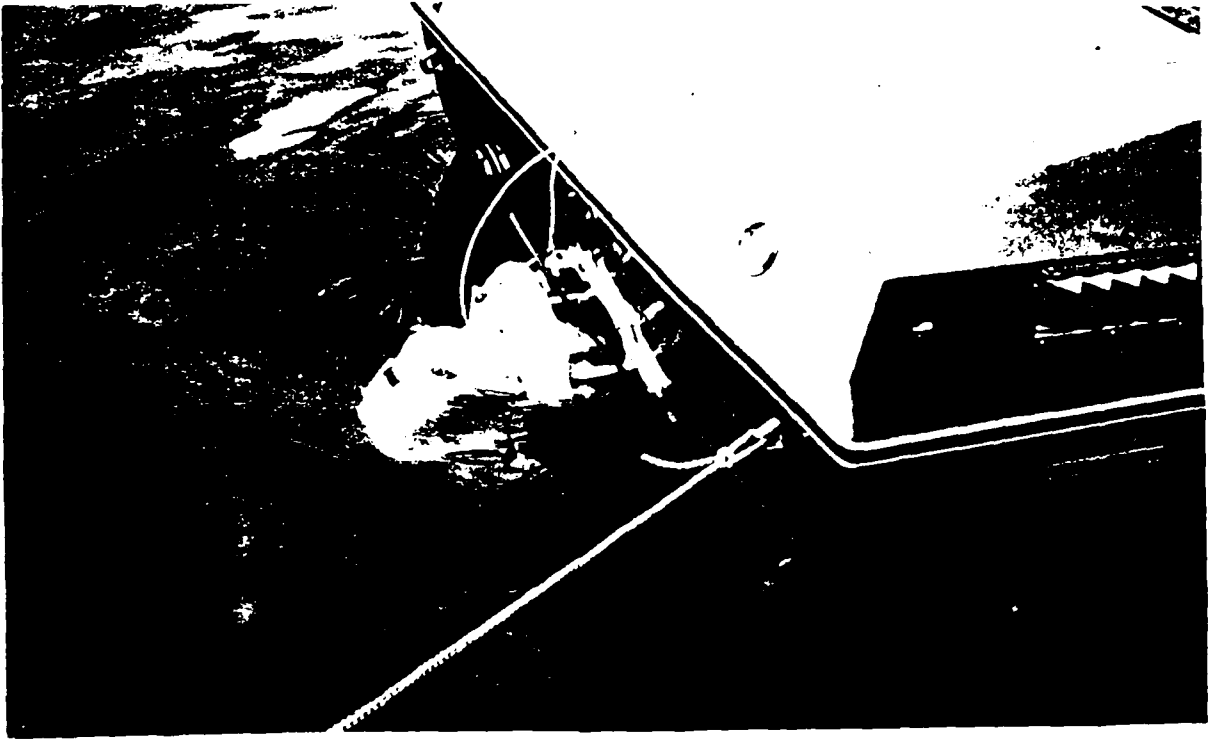
STATIC FLOATING POSITION, SERIES #1 PROTOTYPE
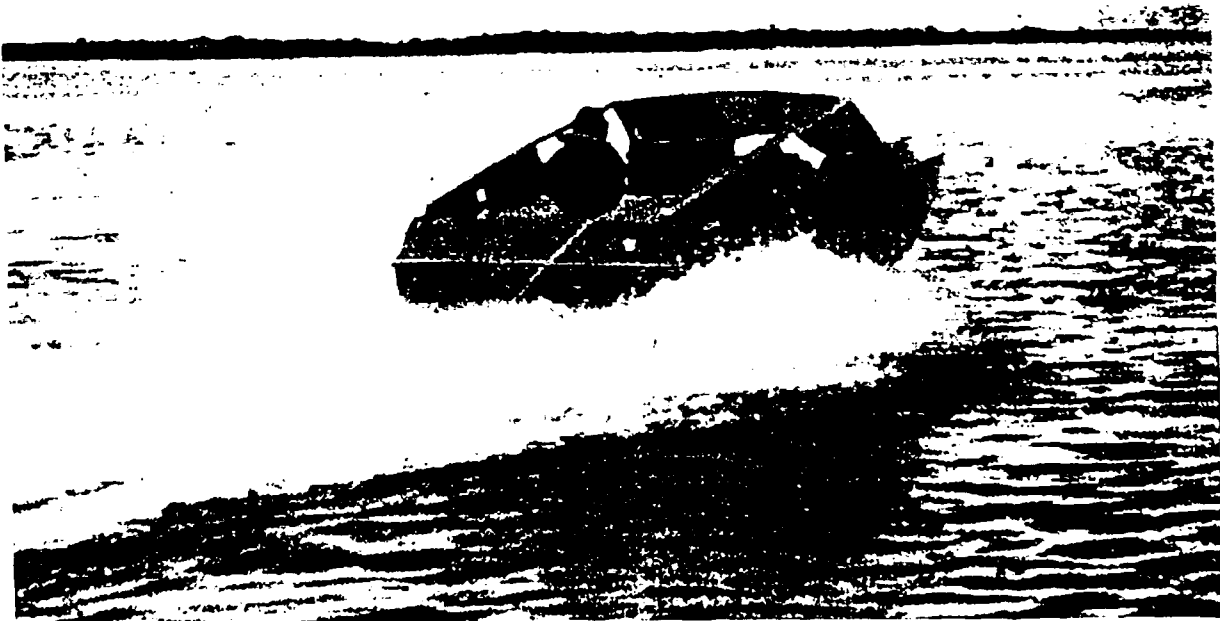
OPERATION OF SERIES #1 PROTOTYPE

SERIES #2, PROTOTYPES & PRODUCTION

CONSTRUCTION

    Rear Intake
    Individual Nozzles
    Separate Reverse Nozzles
    Swivel Steering`

PERFORMANCE

    Speed and Acceleration Equals Propellers
    Steering Very Good
    Reverse Very Good
    Good Fuel Economy
    Good Hump Speed Performance
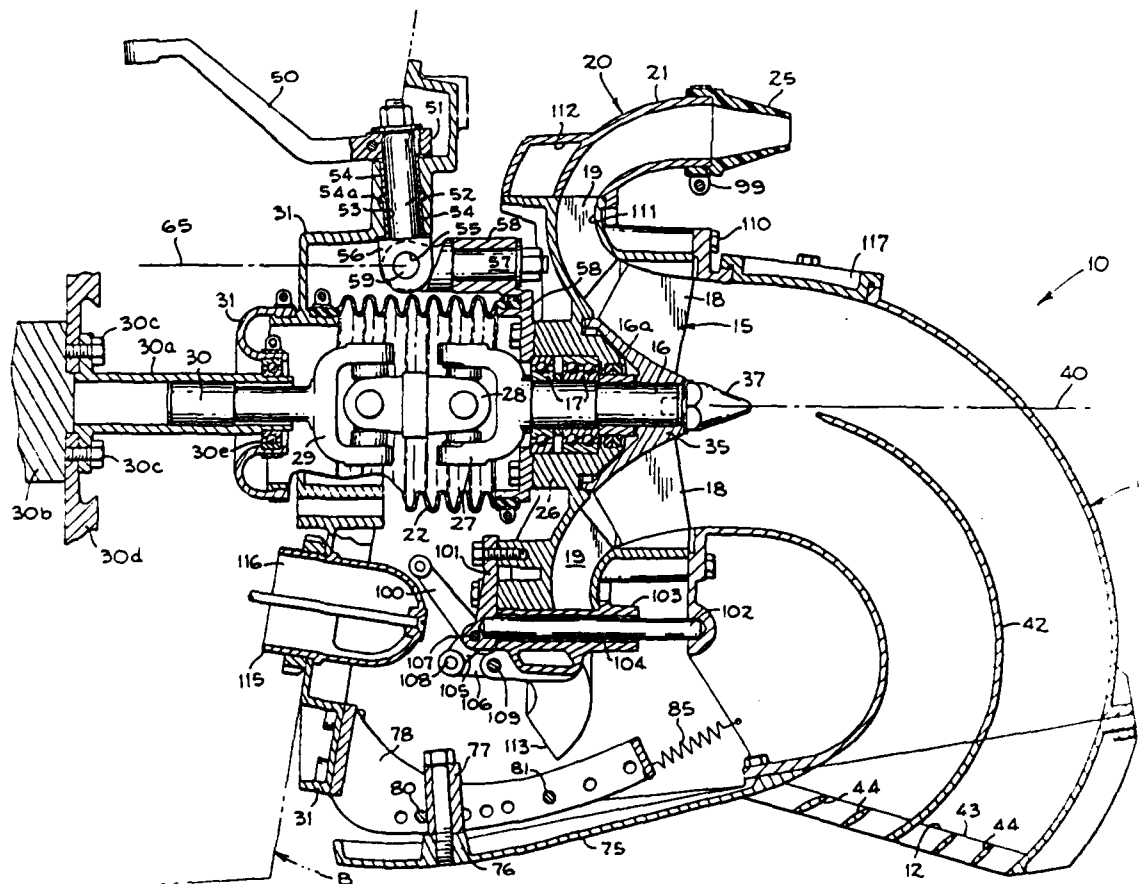
CROSS SECTION, SERIES #2
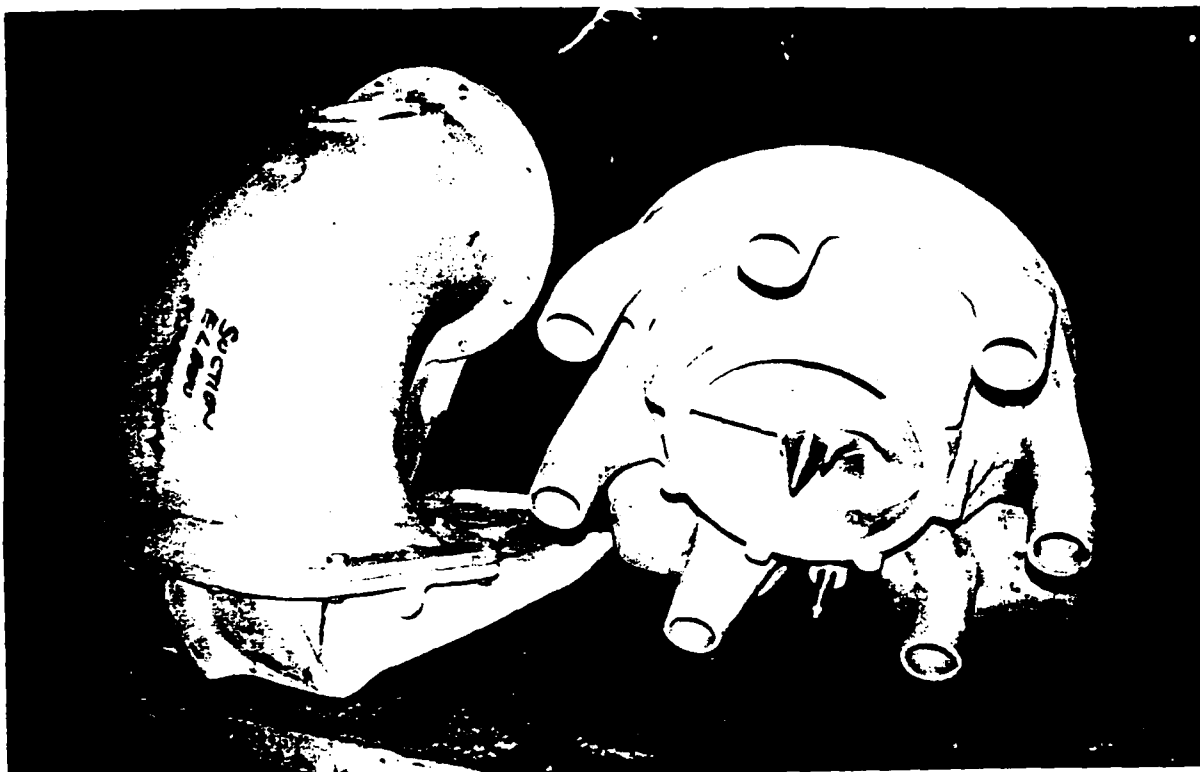
PARTIAL ASSEMBLY, SERIES #2
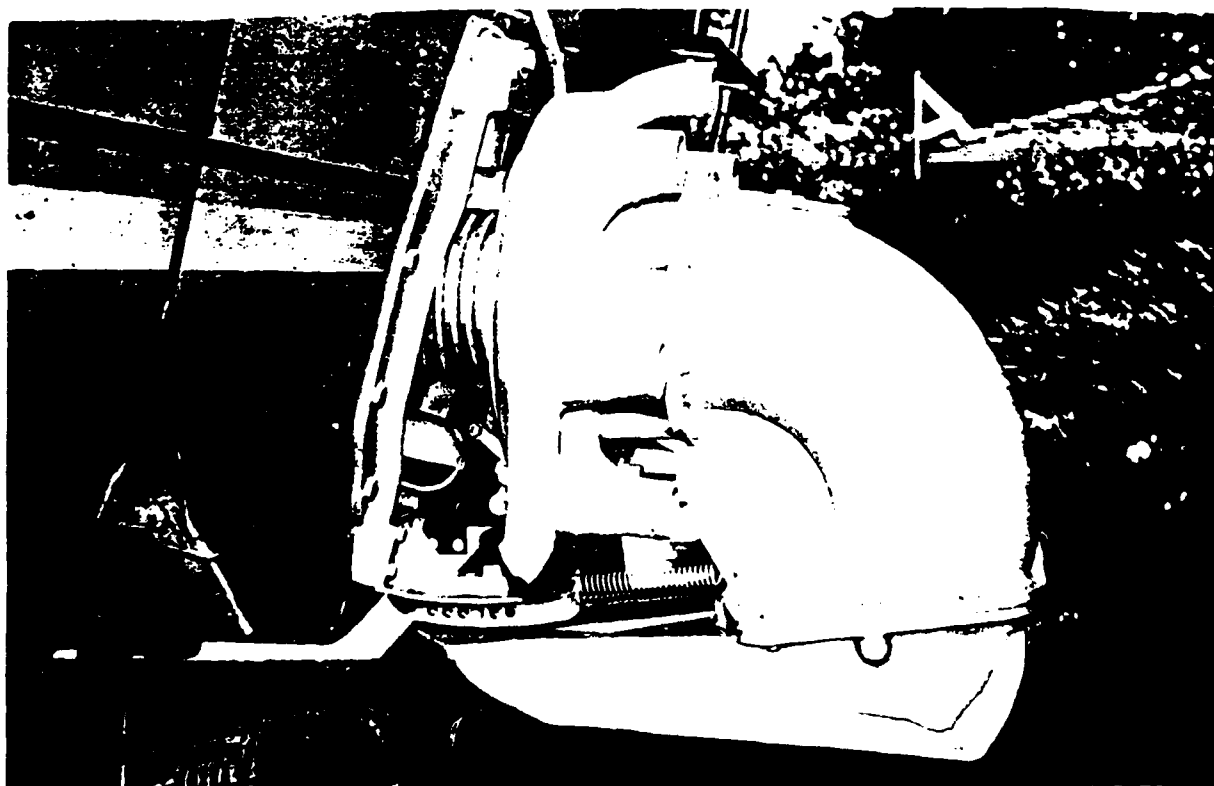
INSTALLATION OF SERIES #2
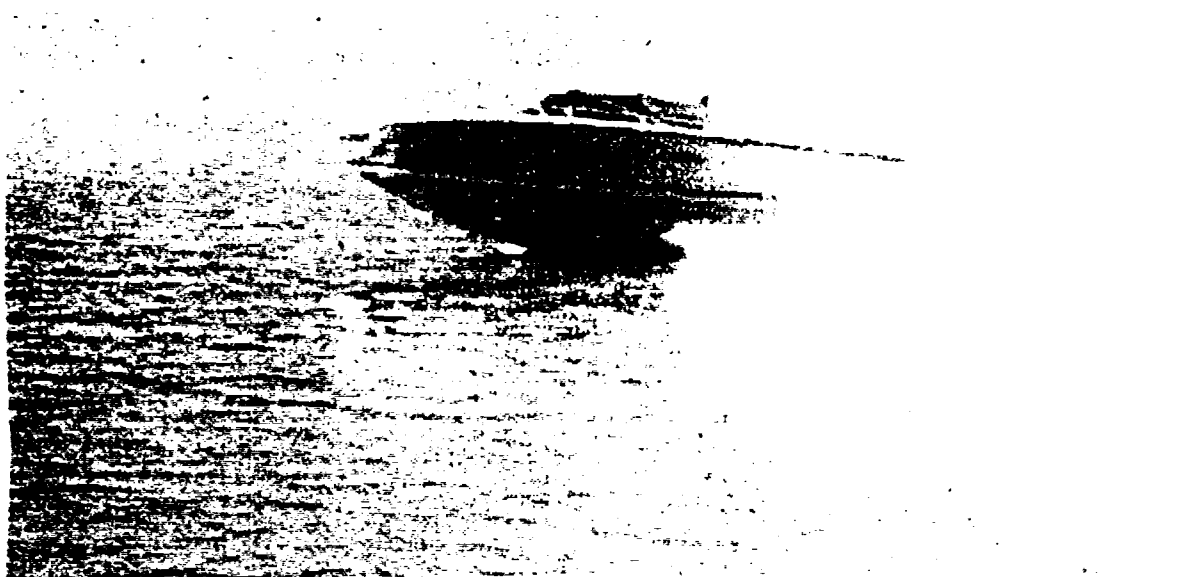
SERIES #2 OPERATION (IN 180 HP SEA RAY SRV190)
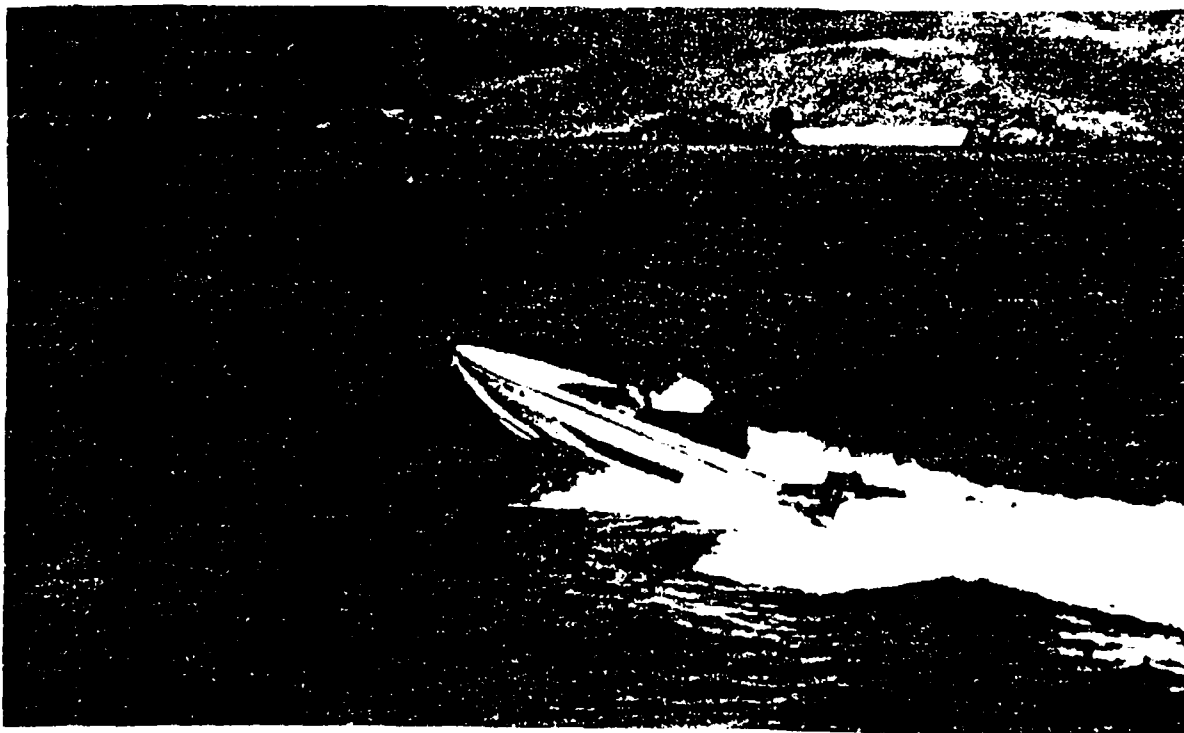
SERIES #2 OPERATION (IN 140 HP SPORTLINE 16)

MARINE DRIVE SYSTEM FUEL TESTS
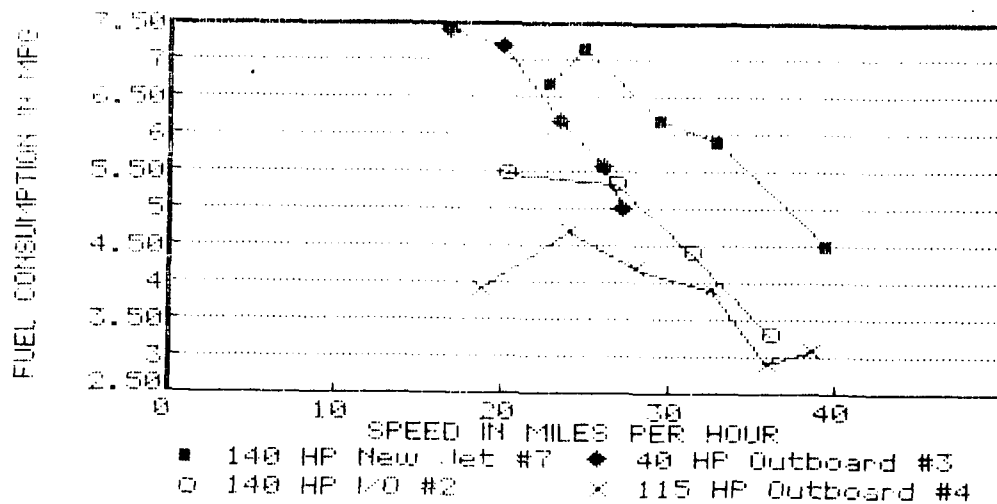
SERIES #2 FUEL CONSUMPTION COMPARED TO PROPELLER DRIVES

MARINE JET SYSTEMS FUEL TESTS
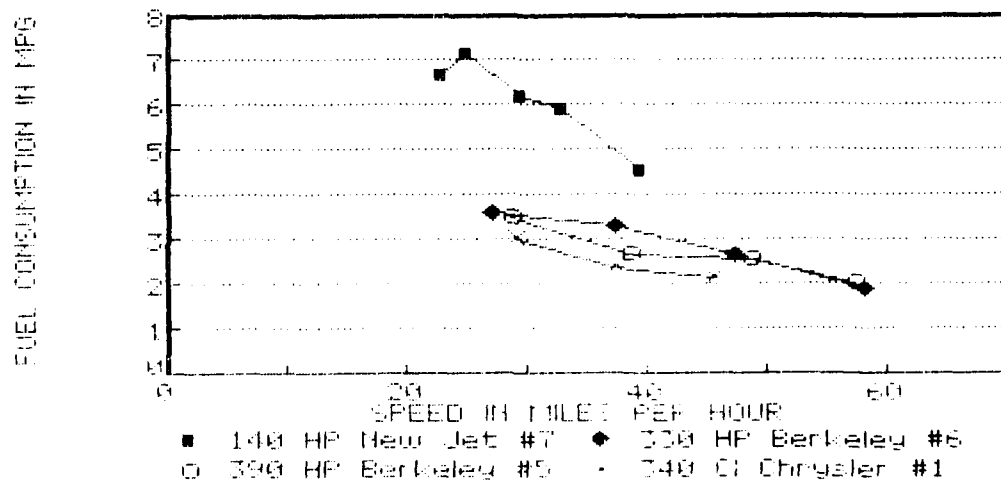
SERIES #2 FUEL CONSUMPTION COMPARED TO OTHER WATERJETS

FUEL ECONOMY TEST COMPARISON

Best Fuel Rate ■   Speed @ Best Rate ◆
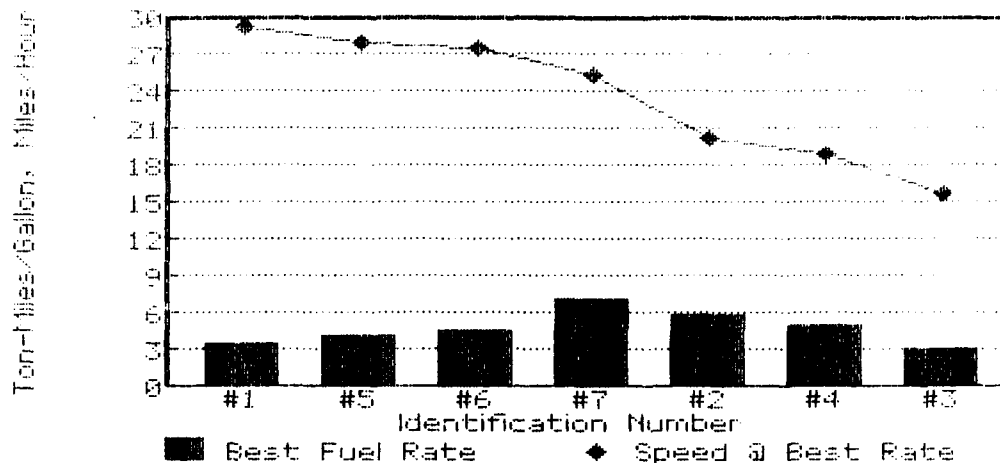
FUEL ECONOMY COMPARISON, CORRECTED FOR DISPLACEMENT

FUEL TEST IDENTIFICATION NUMBERS

#1. Boat: Chrysler Conqueror S III, 18' (Low Profile)
    Engine: Chrysler 340 CID
    Drive: Chrysler Waterjet

#2 Boat: Marlin Venus 16', Tri-hull
    Engine: Mercury 140 HP (Converted Chevrolet 181 CID)
    Drive: Mercruiser I/O Propeller

#3 Boat: Mirro-Craft 14' (aluminum)
    Engine: Evinrude 40 HP Outboard
    Drive: Propeller

#4 Boat: Thunderbird 17' Tri-hull
    Engine: Mercury 115 HP Outboard
    Drive: Propeller

#5 Boat: Kona Maki 18' (Low profile)
    Engine: Oldsmobile 390 HP
    Drive: Berkeley Jet

#6 Boat: Glastron/Carlson CVC-18
    Engine: Oldsmobile 330 HP
    Drive: Berkeley Jet

#7   Boat: Sportline 16' (Low profile)
      Engine: Chevrolet 140 HP, 181 CID
      Drive: Reflex Jet, 7.37"

Note:

      Tests #1 - #6 were conducted by Bob DeVault, Technical
            Editor of Trailer Boats Magazine.

      Test #7 was conducted by Ralph Lambrecht of Outboard Marine
            Corporation

ELBOW LOSSES, KING & BRATER, HYD. HANDBOOK

■ PUBLISHED DATA   ◆ EXTRAPOLATION
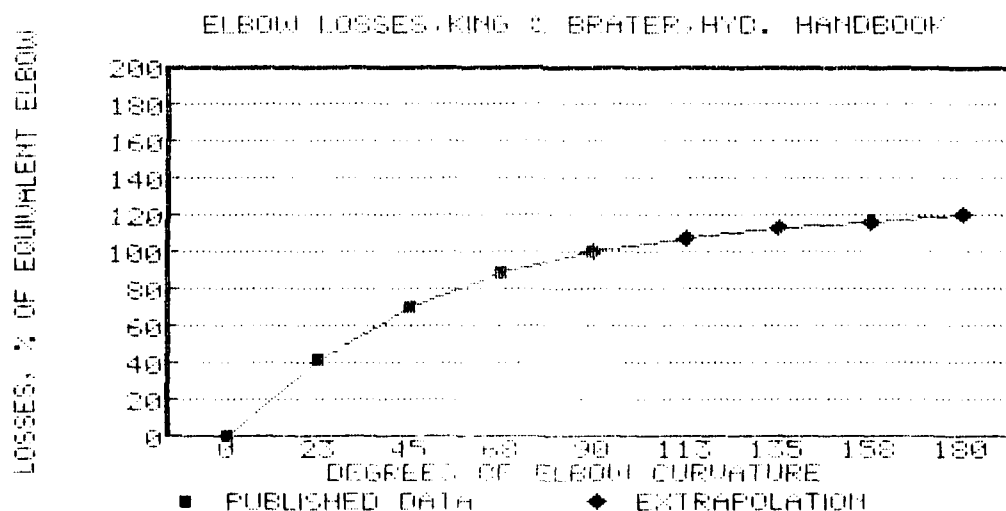
NOTE: The above curve illustrates losses as related to the
amount of curvature in an elbow. It shows losses to be high at
the beginning of the turn, but less for each increment of
curvature. Reference data is for 0 to 90 degrees, but it appears
reasonable that the slope of the curve will continue to decrease
with added curvature. A reversed turn, like some waterjet
inlets,should have higher losses in the second turn.
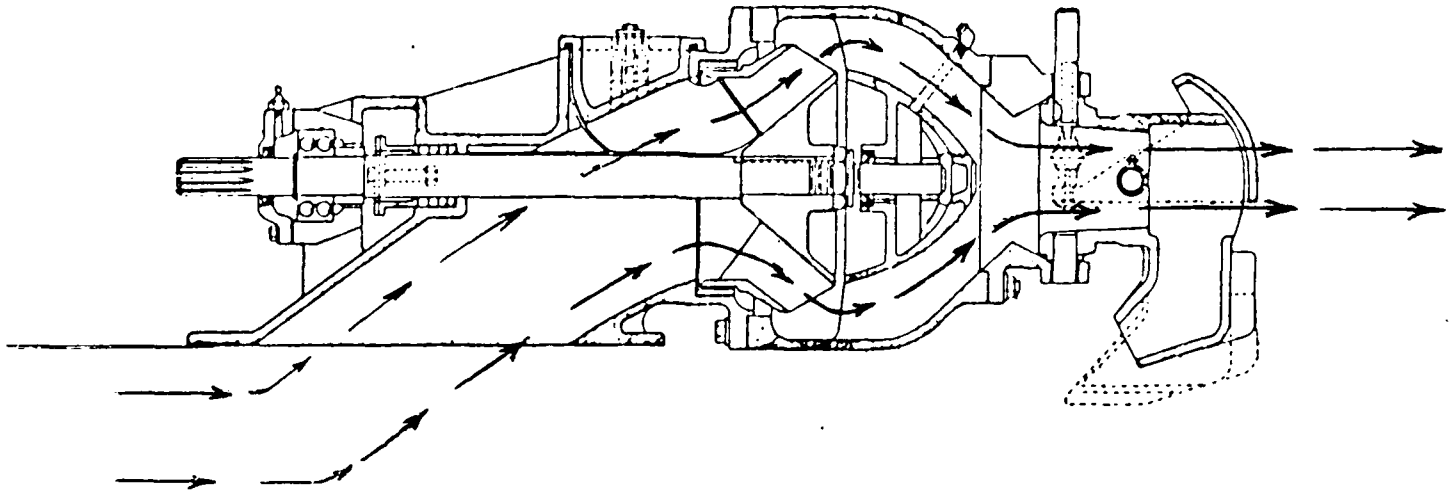
CROSS SECTION OF A CONVENTIONAL WATERJET
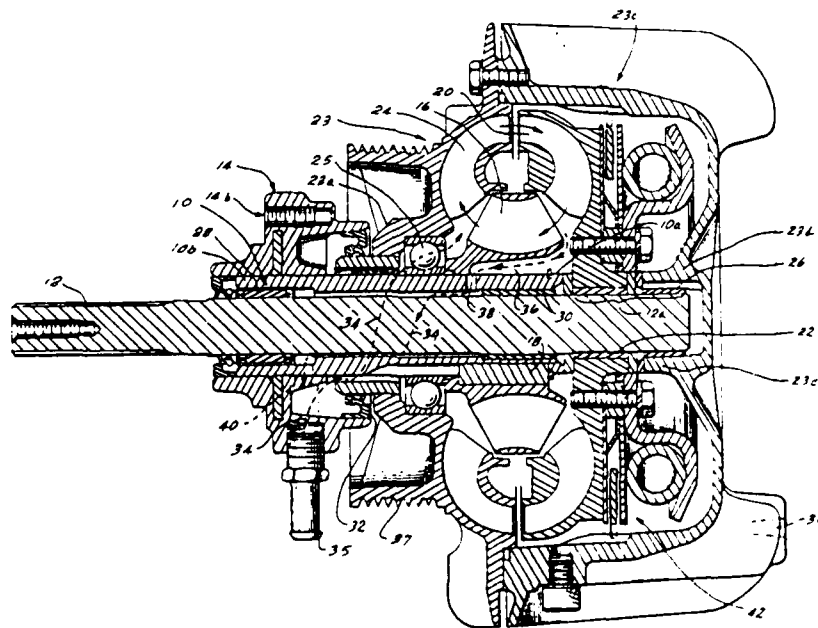
TORQUE CONVERTER CROSS SECTION

TYPICAL TORQUE CONVERTER PERFORMANCE
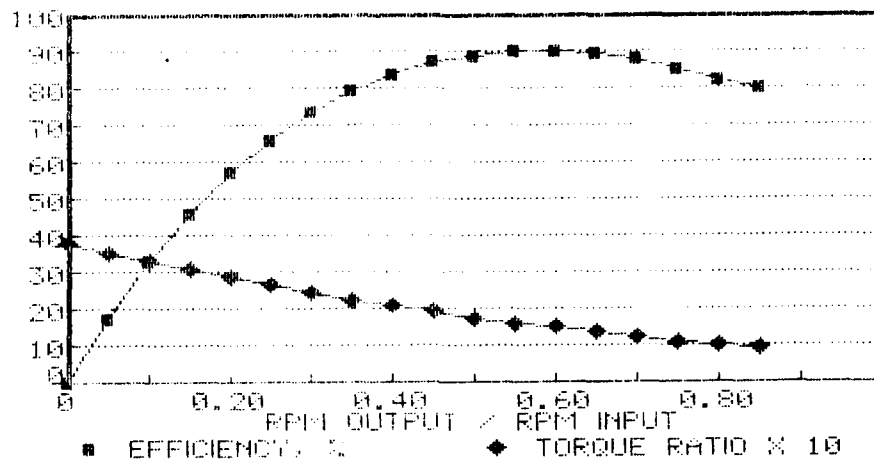
CONVERTERS ARE EFFICIENT IN SPITE OF CURVED FLOW PATHS

120 HP BLADE CONTOURS
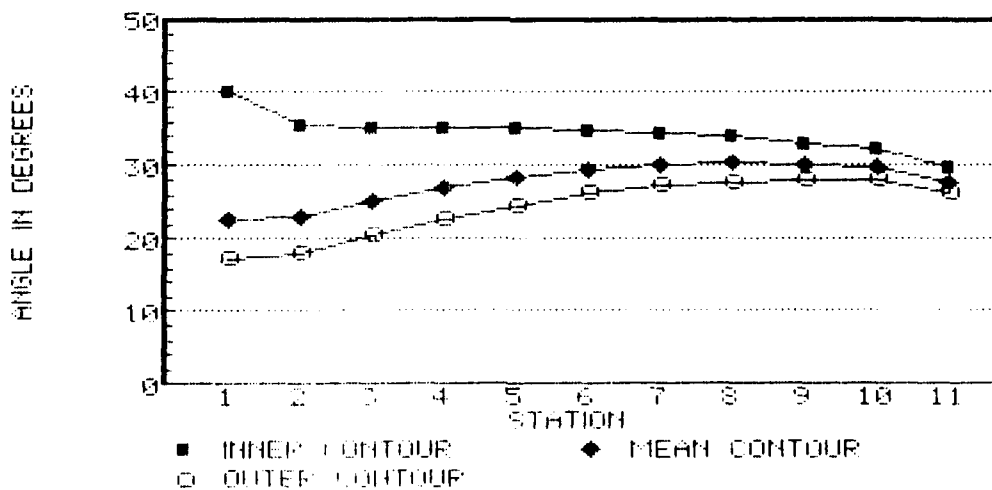
CROSS SECTION CONTROLS BLADE ANGLE BECAUSE AT ANY POINT ON A STATION LINE (COTANGENT OF THE ANGLE)/(RADIUS) IS CONSTANT

UNDERWAY INLET VELOCITY TEST RESULTS

Chart: VERTICAL INCHES FROM SHAFT CL vs INLET VELOCITY AT IMPELLER, FT/SEC

- STANDARD, 9.79 MPH ◆ STANDARD, 16.12 MPH
- ○ STANDARD, 26.25 MPH × REFLEX at 39.0 MPH
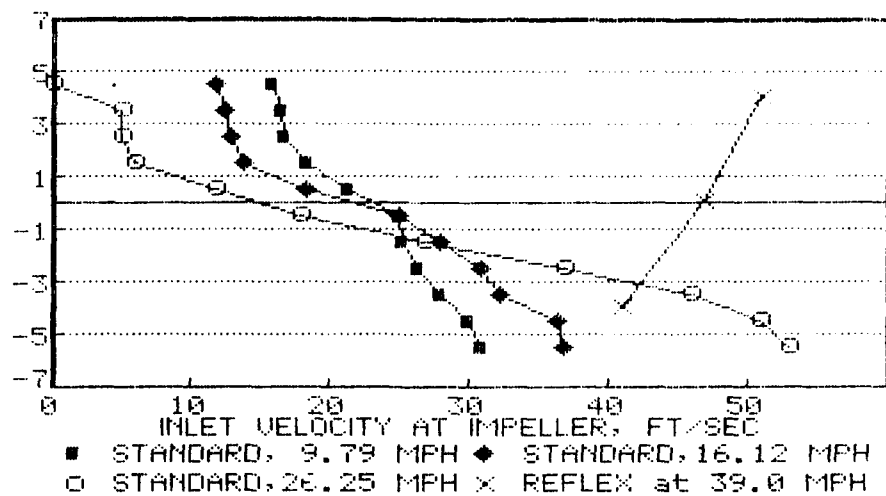
SERIES #2 INLET VELOCITY DISTRIBUTION VS. CONVENTIONAL JET

NOISE @ DRIVER, SEA RAY SRV190/FORD 302

Chart: NOISE LEVEL, DB vs ENGINE RPM

- REFLEX WATERJET ◆ MERCRUISER PROP.
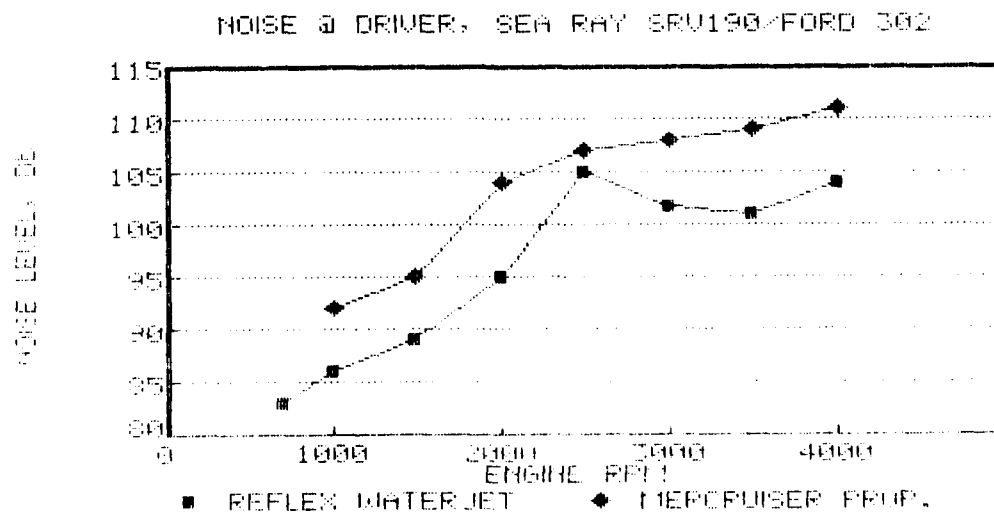
SERIES #2 JET NOISE LEVEL COMPARISON WITH PROPELLER

REFLEX JET, October 10, 1990, Page 13 of 22

BLADE ANGLE VS RPM FOR SPEC. HP
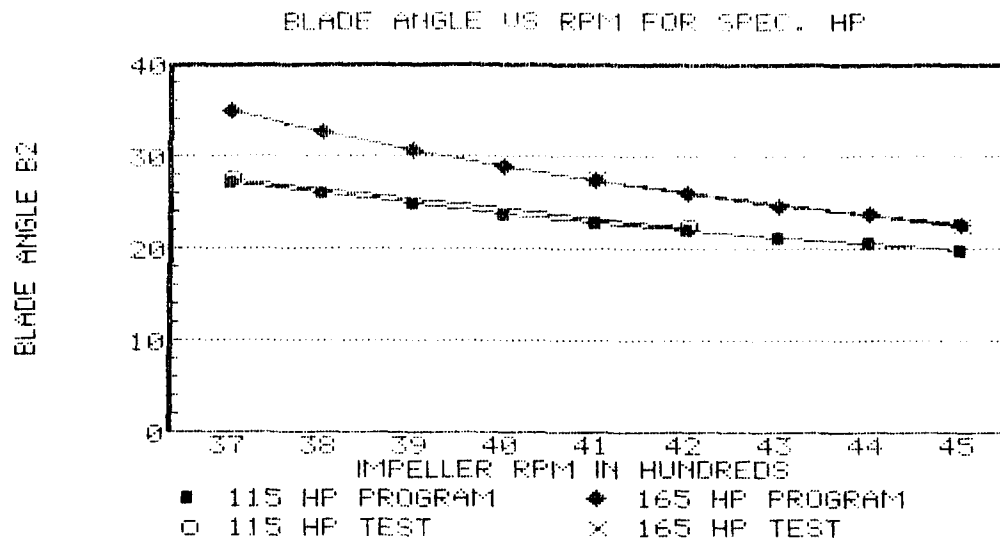
SERIES #2 TEST RESULTS VS. PROGRAM FOR RPM VS. BLADE ANGLE

COMPARISON OF JETOPT9 VS. TESTS
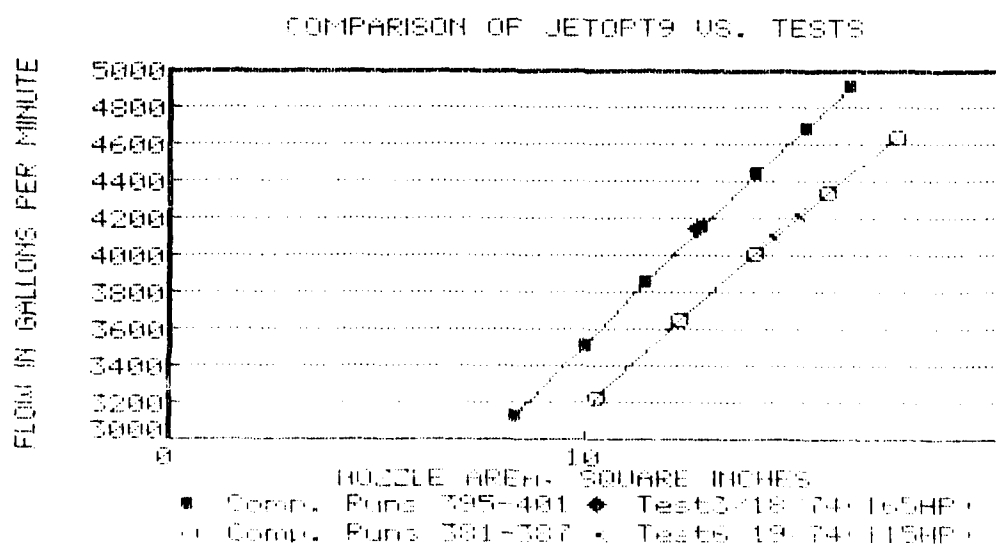
SERIES #2 TESTS VS. PROGRAM FOR FLOW VS. NOZZLE AREA

SERIES #3,
HIGH PERFORMANCE MARINE

CONSTRUCTION

       Rear Intake
       Dual Low Nozzles
       Separate Reverse Nozzle
       Steering Deflector
       General Simplification
       Reduced Size

PERFORMANCE

       No Change In Performance Factors
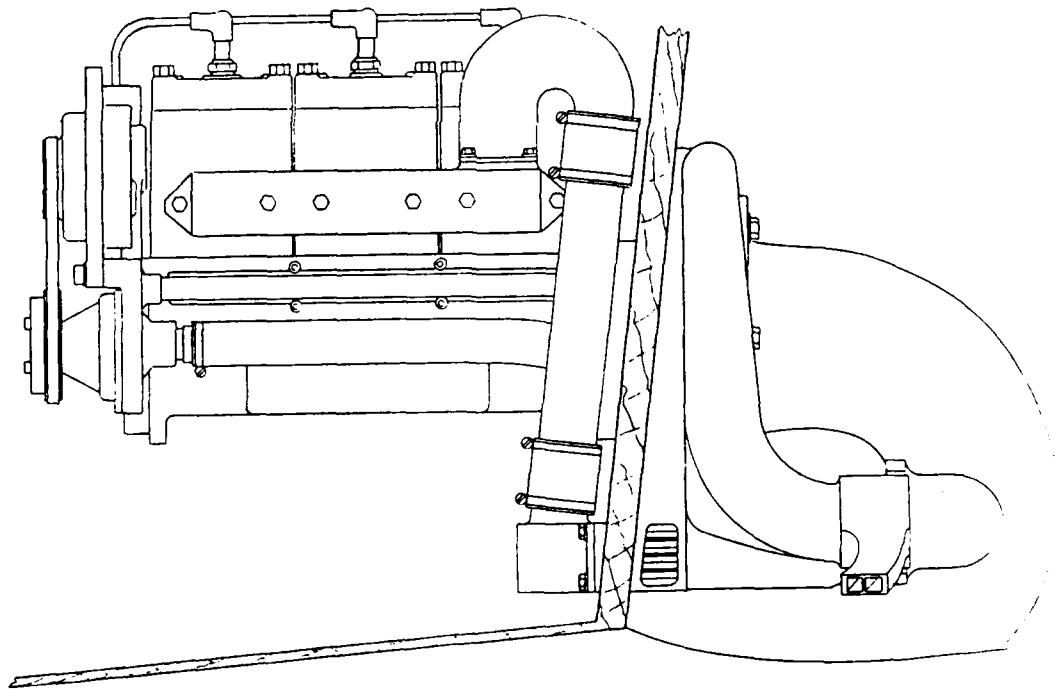
SIDE VIEW, HPM ENGINE AND SERIES #3 WATERJET
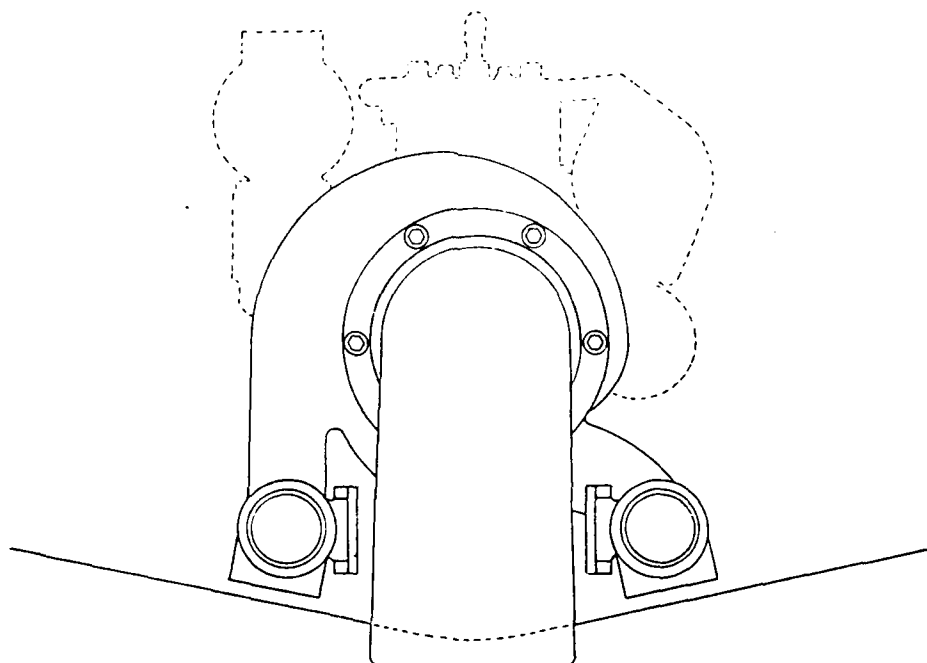
REAR VIEW, HPM ENGINE AND SERIES #3 WATERJET
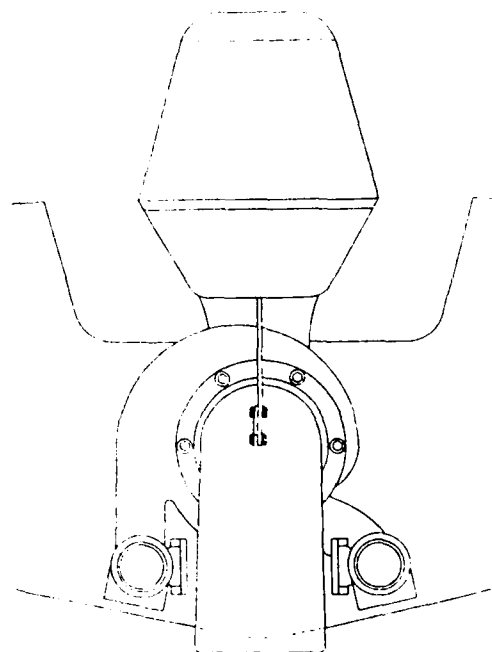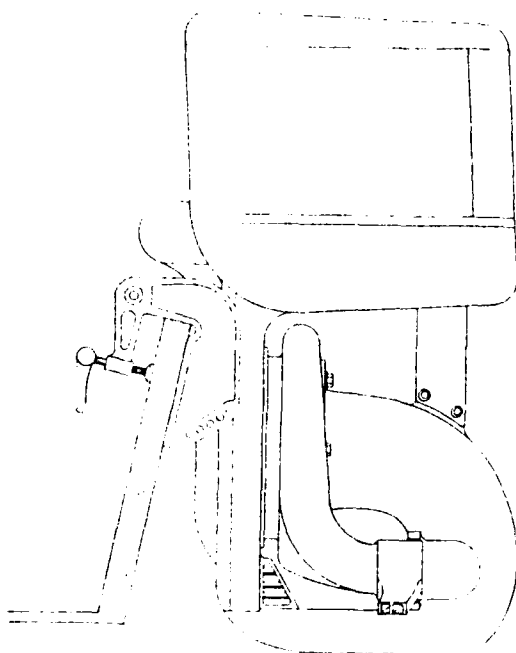
HPM WATERJET OUTBOARD

AAAV ELECTRIC WATERJET CONCEPT

TRANSOM   MOTOR   PUMP   INTAKE ELBOW   NOZZLES (4)

AAAV

TRANSOM FLAP   WATER INLET

AAAV REFLEX JET
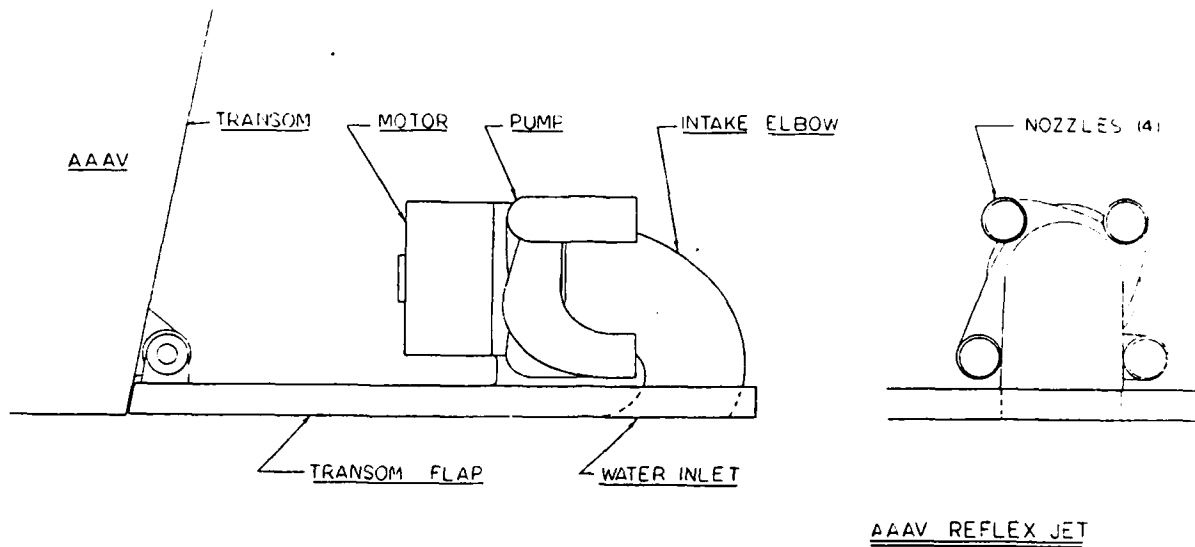
STARTING POINT 16" ELECTRIC JET FOR AAAV

HULL SPEED (MPH)

■ FLOW (GPM/10)   ◆ THRUST (POUNDS)
○ EFFICIENCY*10000   ✕ THRUST TARGET
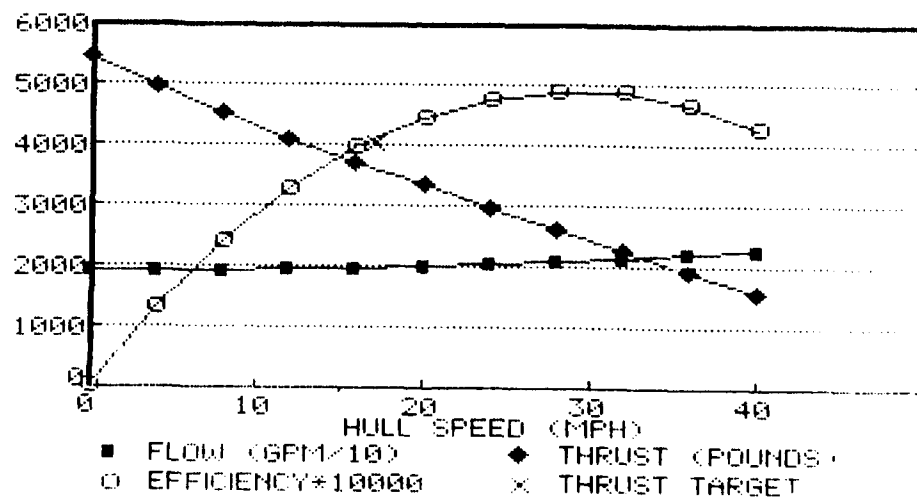
AAAV ELECTRIC WATERJET INITIAL PERFORMANCE ANALYSIS

AAAV WATERJET CONCEPT

CONSTRUCTION

Front Motor For:
- Simple Installation and Repair
- Simplified Gear Reduction
- Simple Electrical Connections

Rear Intake For:
- Low Losses and Good Velocity Distribution
- Improved Hull Hydrodynamics

Quad Nozzles For:
- Fit Available Space
- Good Clearance of Foreign Material

AAAV WATERJET PERFORMANCE OPTIMIZATION

CAPTURE AREA

Optimized For Hump Speed

Use Proven Recovery Factor

Use Proven Drag Factor

Use Proven Recovery & Drag Relation

Provide For Trash Rake Losses

AAAV WATERJET PERFORMANCE OPTIMIZATION

INTAKE ELBOW

Head Loss Factors

- Curvature
- Number of Turns
- Diffusion

Discharge Velocity Distribution

- Conventional Intake
- Elbow Intake

AAAV WATERJET
PERFORMANCE OPTIMIZATION

IMPELLER

Intake
Velocity Distribution
Preferred Angles
Tip Velocity Limits

Discharge
Velocity Distribution
Preferred Angles

Cross Section
Optimized for Best Blade Contour
Minimize Wet Area

AAAV WATERJET
PERFORMANCE OPTIMIZATION

NOZZLE SYSTEM

Controls Flow and Jet Velocity

High Flow Increases Internal Losses
Low Flow Reduces Ideal Efficiency

Flow Optimization

Proprietary Program Will Be Used
Program Has Been Validated By:

Prototype Tests
Comparison With Results From Major Waterjet
Manufacturers

HYDRODYNAMIC INTEGRATION

THEORY

Rear Inlet Avoids Intake Sink In Lifting Area
Of The Hull

Trim Angle Is Reduced

Hull Drag Is Reduced

Intake of Air Is Minimized

Boundary Layer Dump Can Improve
Condition of Water Entering Jet

HYDRODYNAMIC INTEGRATION

TEST RESULTS

Outboard Marine Corporation Tests By R. E. Lambrecht
Show a Five Mile Per Hour Reduction in the Speed
Needed to Plane a Hull When Jet Inlet Was Removed From
the Hull

W. E. Rodler Test Results With the Rear Intake Have
Shown Better Performance Than Can Be Explained by the
Efficiency of the Reflex Jet
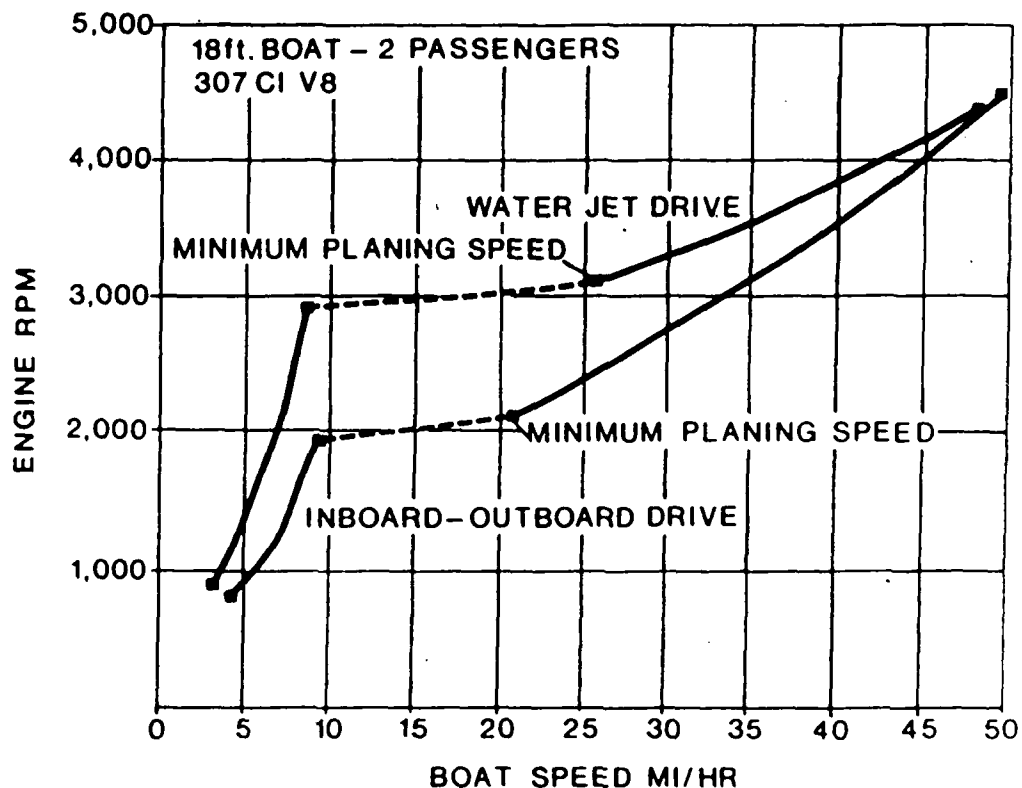
OMC CURVES SHOW EFFECT OF STANDARD WATERJET INLET
ON MINIMUM PLANING SPEED

AAAV WATERJET PERFORMANCE OPTIMIZATION

ELECTRIC DRIVE

Will Be Based On:

U. S. Army TACOM Report No. 13236
By Rodler, Shafer, etc.

Anticipated Major Components:

High Speed PM Alternator
High Speed Induction Motor
Simple Controls

ELECTRIC DRIVE COMPONENTS

HIGH SPEED PERMANENT MAGNET ALTERNATOR

Simple Construction
Small Size
Light Weight
Dependable
Affordable
Very Efficient

ELECTRIC DRIVE COMPONENTS

HIGH SPEED INDUCTION MOTOR

Simple Construction
Small Size
Light Weight
Low Cost
Dependable
Good Efficiency
Easy To Control

ELECTRIC DRIVE COMPONENTS

SIMPLE CONTROL SYSTEM

The Use of an Induction Motor Operating Near
Synchronous Speed Results In:

High Dependability
Minimum Space Requirement
Easy Maintenance
Highest Possible Efficiency

AAAV REFLEX WATERJET PROGRAM

PLANNED ACTIONS

1. Update AAAV Data

2. Prepare Comparison Data

3. Optimize Reflex Design

4. Prepare Reflex Drawing

5. Design Review, Washington, D. C.

6. Develop Data Comparison

7. Make Comparison Matrix

8. Present Final Report

APPENDIX B

REFLEX JET MID PROGRAM REVIEW

by

Waldo E. Rodler
1488 Cherry Garden Lane
San Jose, CA 95125

Presented at Mid Program Review
DTRC, Bethesda, MD

January 29, 1991

HIGH PERFORMANCE MARINE PRODUCTS

Springfield, MO

REFLEX JET MID PROGRAM REVIEW

Technical Presentation

By: Waldo E. Rodler

January 29, 1991
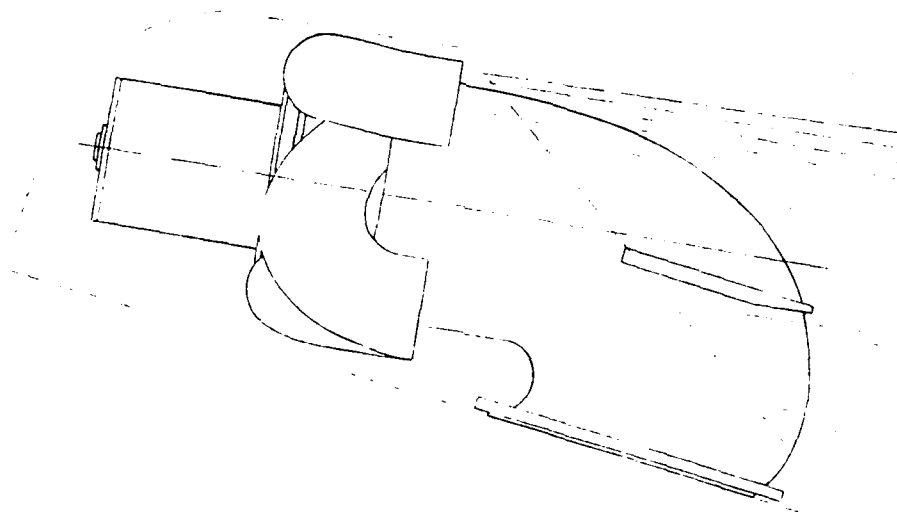
HPM

HIGH PERFORMANCE MARINE PRODUCTS
SPRINGFIELD, MISSOURI

WELCOMES YOU TO THE:

REFLEX JET
PHASE I
MID-PROGRAM REVIEW
JANUARY 29, 1991

HPM

PROGRAM: CONTRACT

1. This is Phase I of a Small Business Innovative Research (SBIR) program.

2. It is DTRC contract N00167-90-0058.

3. Contract administration is by the DTRC Marine Corps Program Office.

4. The Kickoff meeting was held on October 10, 1990

HPM — HIGH PERFORMANCE MARINE PRODUCTS
SPRINGFIELD, MISSOURI

KEY-CONTRACT PERSONNEL:

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HPM — INTRODUCTION: HISTORY

1. The concept was developed during a torque converter development program for KOMATSU.

2. Torque converter technology was transferred to the waterjet.

3. Three prototypes were built and tested.

4. The results were comparable with other existing waterjets.

HPM INTRODUCTION: HISTORY

1. A redesign was made based on the data gathered in the tests of the first prototypes.

2. Three prototypes were built.

3. Tests showed excellent performance and durability.

4. A limited production run of 50 unit was made and sold.

5. A total of six spare parts were sold in the following five years.

HPM INTRODUCTION: HISTORY

CURRENT COMMERCIAL ACTIVITY:

1. Design is in process for a compact transom mounted water jet with inboard engine.

2. Design in in process for an outboard engine and jet.

3. Program is paced by engine design and production facility.

21

JET

JET

14 STEP

24 OVER ALL

TRANSOM FLAP

UNIQ

60

REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 4

REFLEX WATERJET MID PROGRAM REVIEW, January 29, 1991, Page 5

AAAU WATERJET PERFORMANCE RUN 901031.5

(chart)
HULL SPEED IN MPH

■ THRUST IN POUNDS ♦ FLOW, GPM/10
○ P. C. X 10,000 × 18 MPH DESIGN SPD.

SPECIFICATIONS:

HPM
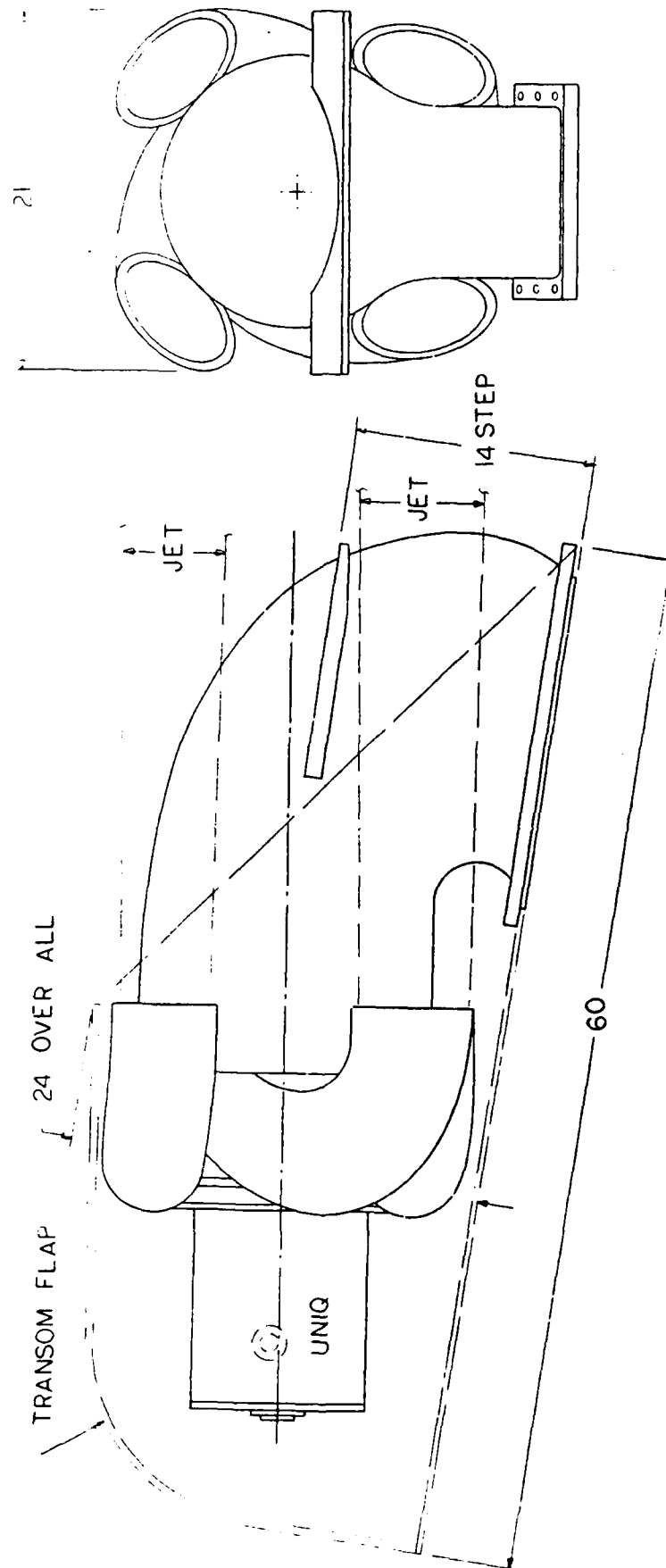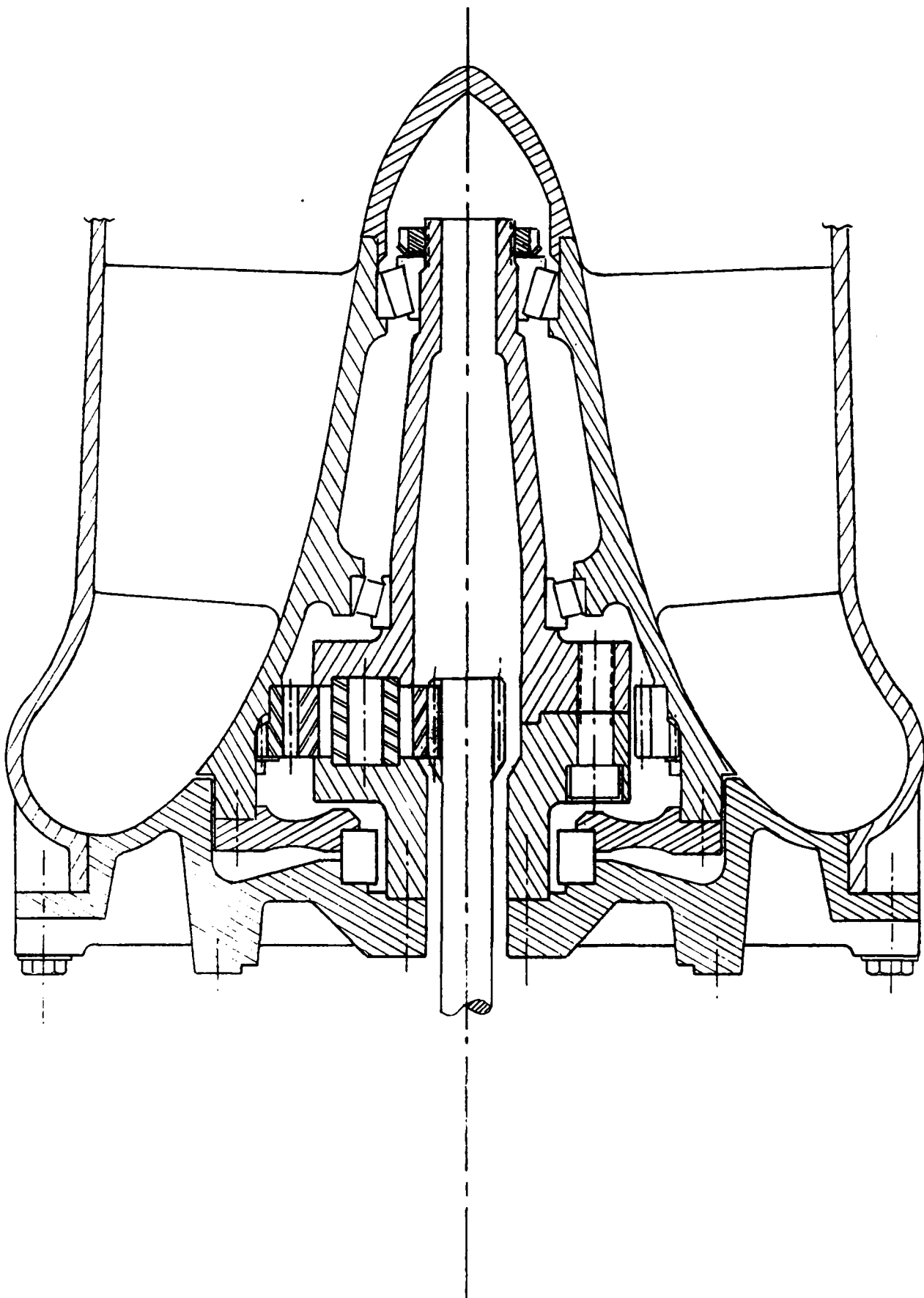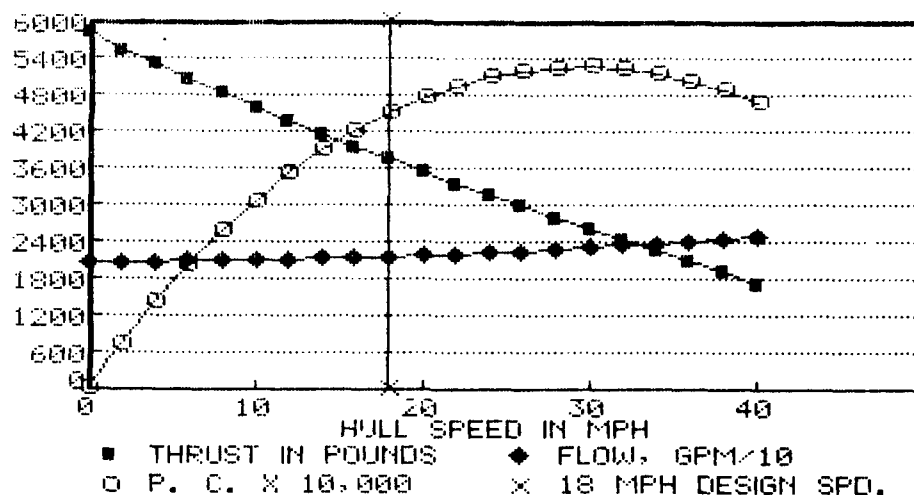
1. Thrust at 18 MPH	3775 Lbs.
2. Shaft Horsepower	400
3. Shaft RPM	1750
4. Impeller diameter	16.1 Inches
5. Impeller tip velocity	123 Ft/Sec
6. Nozzle Area	104.91 In^2
7. Weight with intake and motor	551 Lbs.
8. Life (aluminum impeller)	144
9. Size (inches)	<52 L x 21 H x 21 W

HPM | SIZE OPTIMIZATION

1. Thrust curves are broadly peaked for optimized designs.

2. Weight increases exponentially with size.

3. A 16" size looked good:

   96.8% of the thrust of the 20" size.

   57% of the weight of the 20 " size.

4. A 16.1" size was selected to facilitate direct comparison with the DTRC jet.

EFFECT OF SIZE ON THRUST AND WEIGHT
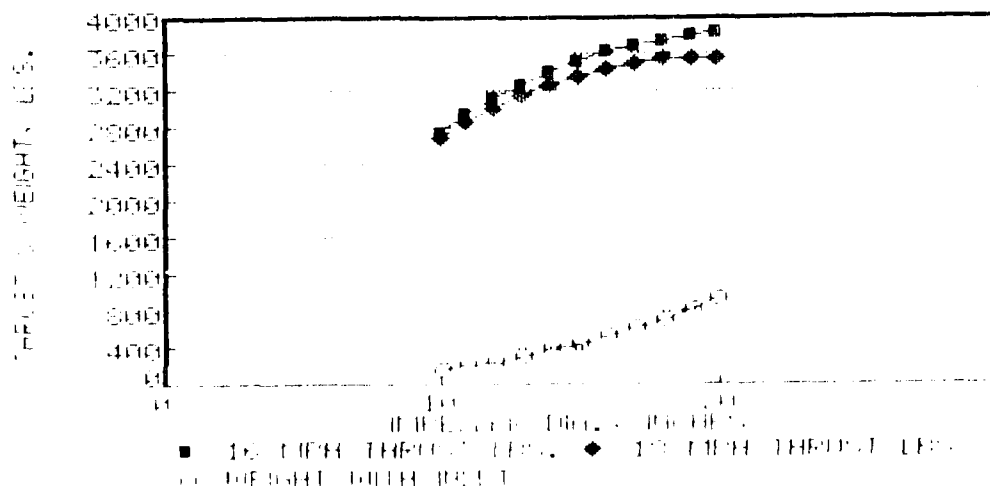
HPM — SIZE OPTIMIZATION

EFFECT OF SIZE ON THRUST MARGIN

Dia. In.	Thrust Lbs.	Dry Wgt Lbs.	Water Wgt Lbs.	Total Wgt Lbs.
20	3563	919	503	1,422
16	-3449	- 526	- 326	- 852
Net	114	393	177	570

Drag increase at d/D = 0.2, 0.2*570 = 114 Lb

Thrust increase with 20" jet .... = 114 Lb

Change in thrust margin .... = -0-

HPM — IMPELLER SPEED

INCREASED IMPELLER SPEED

Permits higher motor speeds with
a single stage of gear reduction.

Higher motor speeds tend to:

1. Reduce motor torque
2. Reduce size
3. Reduce weight

Motor manufacturers are quantifying
these benefits.

HPM   IMPELLER SPEED

1. **Current design is based on 1750 RPM.**

2. **Increased RPM increases Specific Speed which slightly reduces pump efficiency.**

3. **Increased RPM increases Suction Specific Speed which reduces cavitation margin.**

4. **Increased RPM permits higher motor speed with a single stage of reduduction gearing, which reduces size, weight and cost of motor and controls.**

5. **Final selection depends on characteristics of the selected motor.**

EFFECT OF RPM ON THRUST & SPEC. SPEEDS
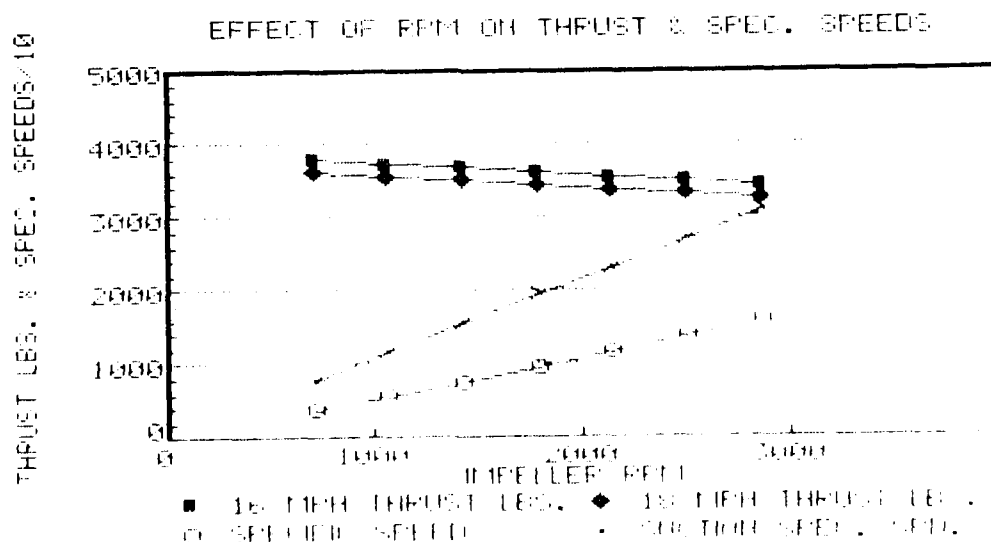
HPM — IMPELLER SPEED

EFFECT ON THRUST

RPM	Thrust, lbs.
1,250	3,533
1,750	3,454
Loss =	79

EFFECT ON CAVITATION

RPM	Suction Specific Speed
1,250	13,381
1,750	18,733

Comparison: 7.34 operated at 27,000

HPM — CAVITATION

Cavitation is a critical consideration

1. It can cause catastrophic loss of performance.

2. It can seriously limit life by eroding impeller.

Cavitation considerations limit the water flow through a jet.

High flow is required in low speed hulls because it improves efficiency:

$$\text{Ideal efficiency} = \frac{2 \times (\text{Hull speed})}{(\text{Hull Speed} + \text{Jet Speed})}$$

HPM CAVITATION

LIMITING RISK BY ANALYSIS:

Possibility of cavitation is measured by conventional suction specific speed analysis and by "VCF" (Velocity Conversion Factor). VCF is the part of the total head at the impeller eye that is velocity head.

Similar analytical methods have been:
1. Published by George Wislicenus
2. Used by Merle Huppert, Aerojet

Effectiveness has been confirmed by extensive tests of the earlier reflex waterjets.

CAVITATION MARGIN VS. 18 MPH THRUST

THRUST POUNDS

3850
3800
3750
3700
3650
3600
3550
3500
3450
3400
3350

.45   .55   .65   .75

VELOCITY CONVERSION FACTOR (VCF)
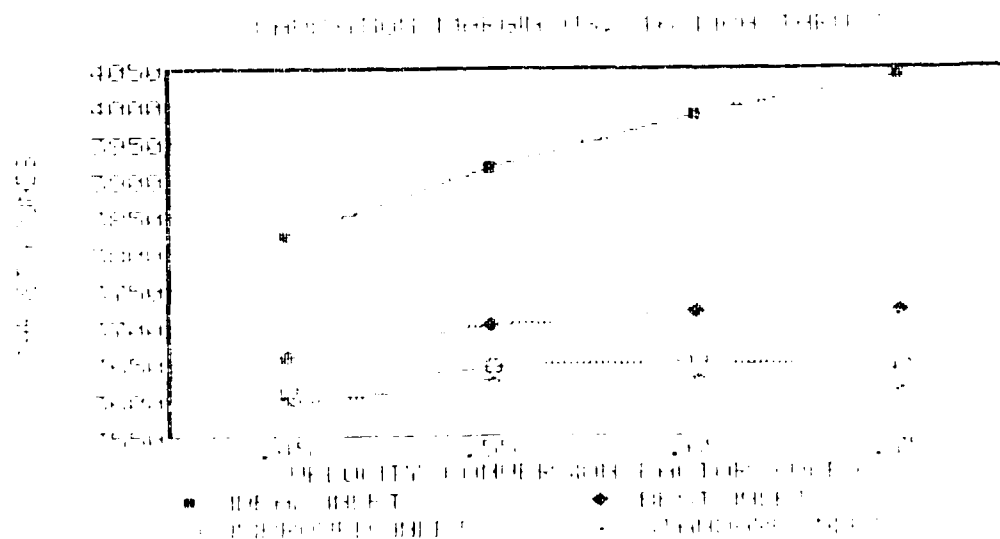
■ IDEAL INLET   ◆ BEST INLET
○ IMPROVED INLET   ✕ STANDARD INLET
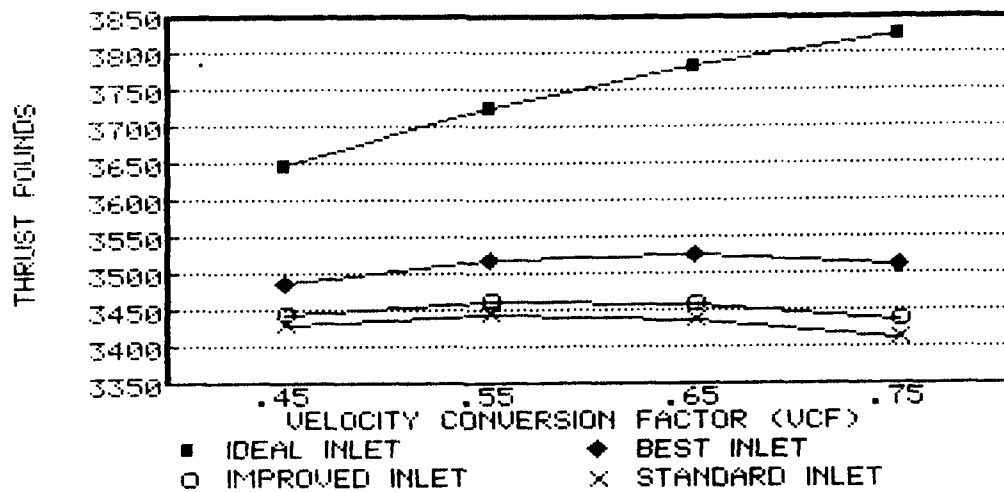
HPM **CAVITATION**

LIMITING RISK BY PRACTICAL DESIGN

Significant cavitation factors of prior
successful designs are retained:

1. Inlet configuration and velocity

2. Impeller tip velocity

3. Impeller inlet angles

4. Impeller contours

EFFECT OF LIFT

"LIFT" is the vertical offset from the static waterline to the mean height of the nozzles.

The energy required to lift the water is a significant loss in the low head, high mass flow waterjets required low speed applications.

The low height of the AAAV waterjet minimizes this loss.

Two low mounted nozzles would minimize this loss, but would increase the installed width of the waterjet.

EFFECT OF LIFT ON THRUST
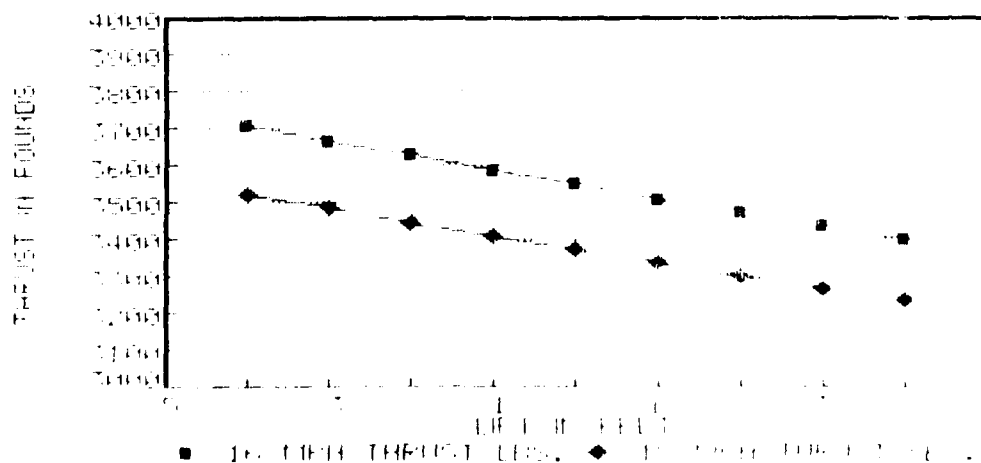
HPM — INLET ELBOW

MAIN DESIGN PARAMETERS ARE RETAINED FROM PREVIOUS SUCCEFUL DESIGNS:

1. Water velocity
2. Convergence
3. Inside radius
4. The r/d ratio
5. Hydraulic radius

HPM — INLET DRAG FACTORS

INLET FACTORS USED IN THE ANALYSIS:

Inlet drag .... : 0.05

Inlet velocity head recovery : 0.75

EXTENSIVE FREERUNNING HULL TESTS OF REASONABLE INLET DESIGNS SHOW:

1. Significant variations in these values.

2. No measurable change performance.

3. "There's no free lunch." Design features that improve recovery also increase drag.

HPM   LIFE ESTIMATE

Results of life tests of 7.34" jet with 356-T6 aluminum impeller.

1. <u>Clear water test:</u>

   300 hours = 0.012" tip wear

   Wear rate = <u>0.00004"</u> per hour

2. <u>Sandy beach test:</u>

   6 hours   = 0.030" tip wear

   Wear rate   = <u>0.005"</u> per hour

HPM   LIFE ESTIMATE

<u>ESTIMATED LIFE IN AAAV APPLICATION:</u>

1. <u>Typical mission:</u>

   Clear water, 2.5 hours = 0.00010"

   Surf zone, 5 minutes   = 0.00042"

   Wear per mission   = <u>0.00052"</u>

2. <u>Life:</u>

   0.030" / 0.00052 = <u>57 missions</u>

   At 2.5 hr/mission = <u>143 hours</u>

NOTE: 0.030" wear was acceptable in 7.34" jet.

HPM — WEIGHT ESTIMATE

1. The weight estimate is based on the scale weights of a similar 7.34" jet

2. Total weight 7.34" jet   94 lbs
   Less transom bracket   −8 "
   Less swivel mounting   −11 "
   Net comparable weight   75 "

3. Estimate for 16.1" jet (from SAE 740281[*])

$$W_2 = W_1 * (D_2/D_1)^{\wedge}3 * (P_2/P_1)^{\wedge}0.7$$

$W_1 = 75, \quad D_1 = 7.34, \quad P_1 = 65.32$
$D_2 = 16.1, \quad P_2 = 28.40$
$\underline{W_2 = 442 \text{ LBS.}}$ (with intake, without motor)

[*] By Rudnicki & Sjogren, Aerojet Liquid Rocket

HPM — WEIGHT ESTIMATE

ELECTRIC WATERJET WEIGHT:

1. Jet weight with intake   442 lbs.

2. Electric motor   109 lbs.
   (Uniq mobility data)

Total weight   551 lbs.

NOTE: Estimate assumes use of 356−T6 aluminum castings for major parts. Weight reduction is anticipated by use of graphite/epoxy, silicon carbide aluminum, etc.

HPM CONVERGENT DUCTS

"The author has found that a reducing suction elbow is just as efficient as a straight taper, an indication that the bad effect of an elbow on velocity distribution is fully neutralized by the steadying effect of a convergent channel."

From:

Centrifugal and Axial Flow Pumps
By: A. J. Stepanoff
John Wiley & Sons, New York, NY
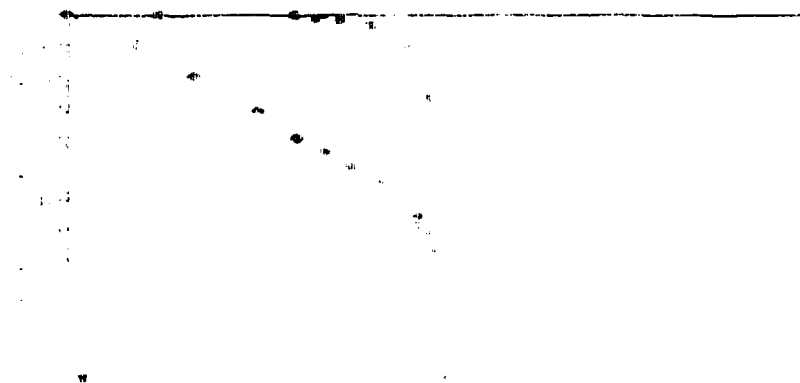
REFLEX JET AXIAL VELOCITY
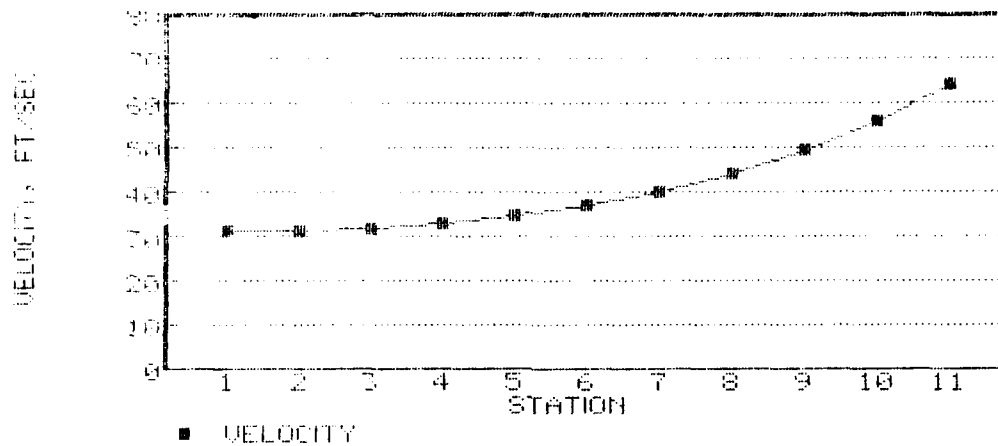
JET AXIAL VELOCITY COMPARISON

INTERNAL FLOW

HPM IMPELLER DESIGN
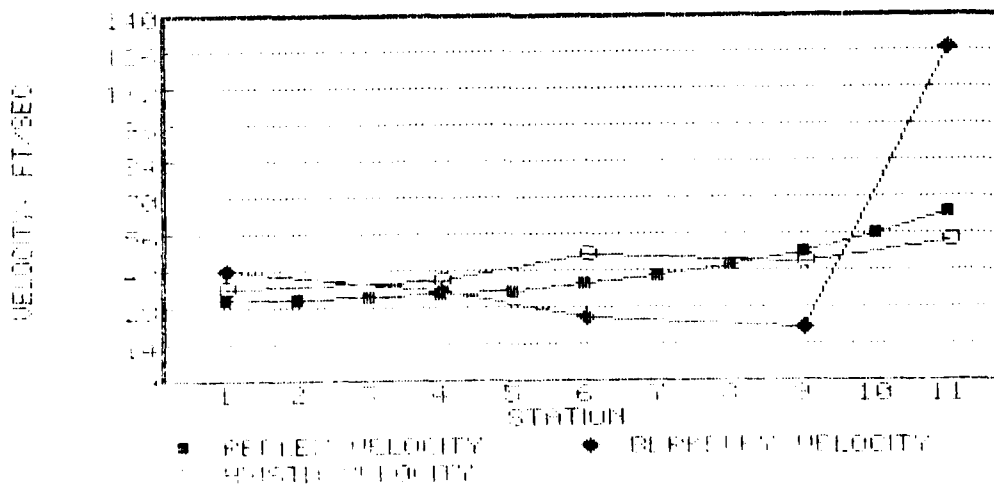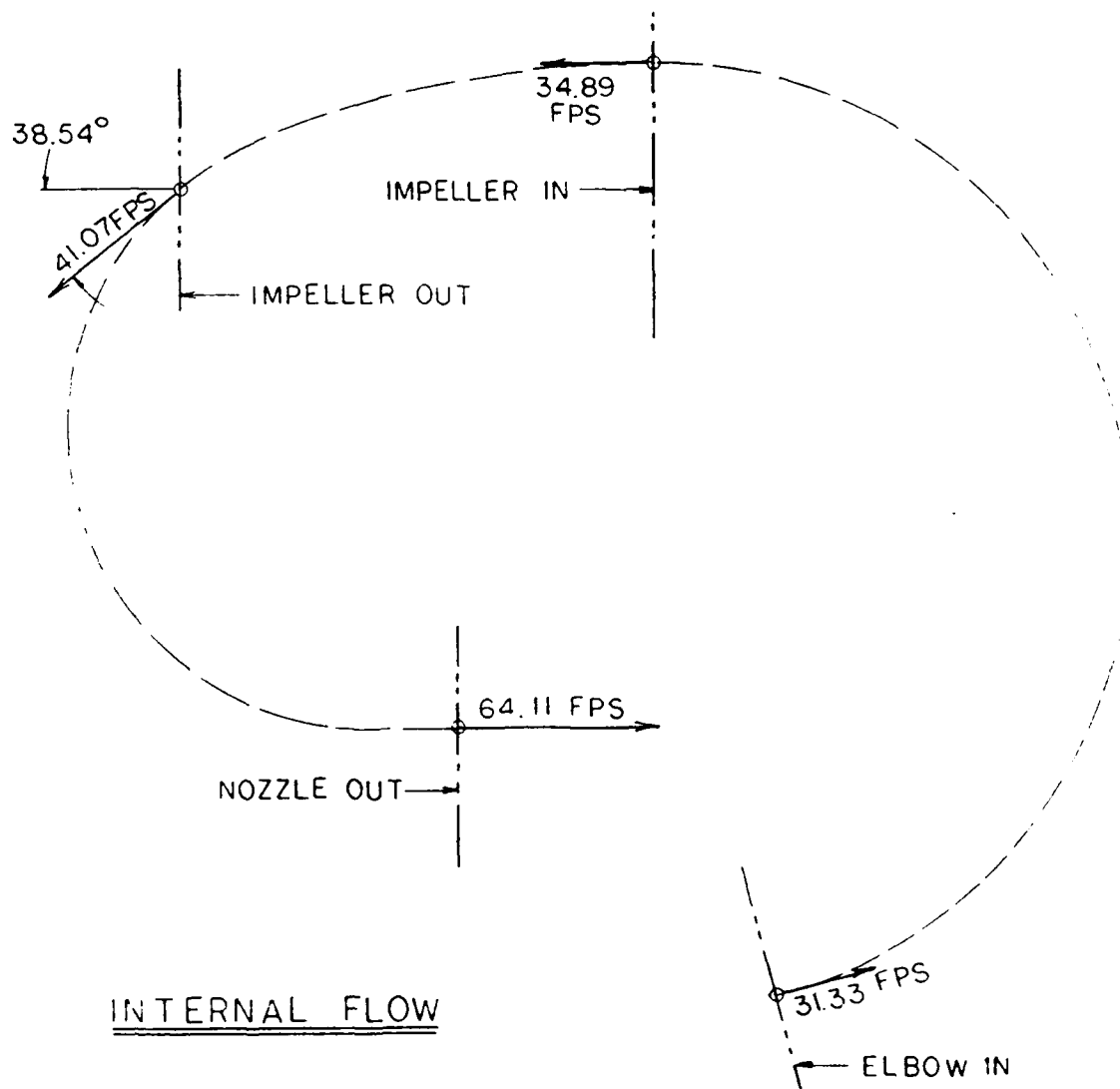
Tangential velocity distribution:

FORCED VORTEX

FREE VORTEX

BLADE ANGLES FOR 16.1" HHHO WATERJET
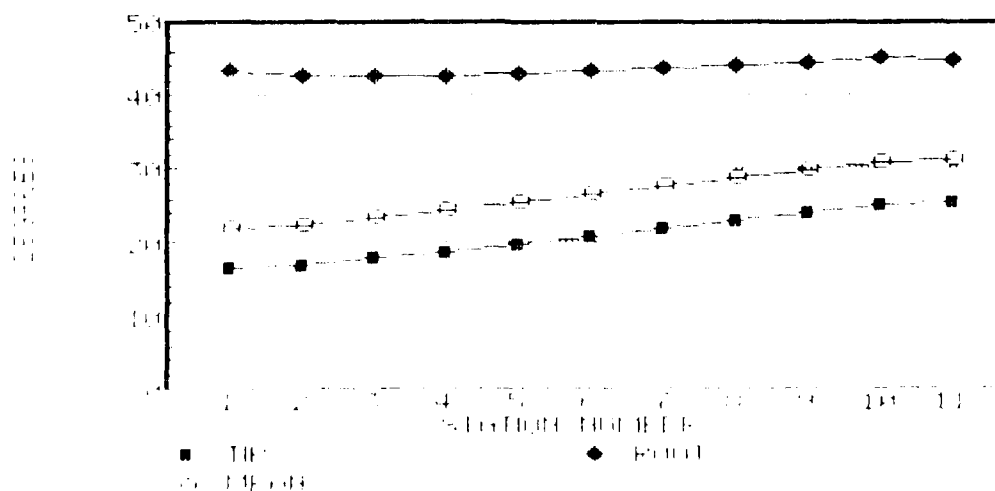
HPM REDUCTION GEARING

1. A preliminary gear set has been selected on the basis of a conventional analysis for beam strength, surface compressive stress and anticipated ratio.

2. Stress level is slightly below the level that apparently was used in the Westinghouse motor and is slightly conservative for military vehicles.

3. Preliminary 12 Pd gear set:

Dimension	Sun	Planets	Ring
Tooth number	15	39	93
Pitch diameter	1.250	3.250	7.750
Outside diameter	1.417	3.417	7.917
Face Width	1.100	1.050	1.100

HPM MAINTAINABILITY

PERIODIC MAINTENANCE:

Motor/gear lube, level and condition

Tip wear check

FIELD REPAIR:

Four bolts release motor/gear/impeller assembly

DEPOT REPAIR:

Motor/gear/impeller assembly will require careful and clean repair

HPM   MOTOR SOURCES

STATUS OF MOTOR SUPPLIERS:

Source	Comments
EML Research	Active, very interesting alternates+direct drive
Inland Kollmorgan	Active but slow
Martin Marrietta	Not interested
Satcon Industries	Active, heavy, conservative + light alternate
Uniq Mobility	Active, light weight, and in depth technical data
Westinghouse	Active, good, understand use and integration

HPM   CONTINUING EFFORT

1. MOTOR SOURCE DESIGN COORDINATION.

2. STUDY NOZZLE/COLLECTOR IMPROVEMENTS TO REDUCE WIDTH BY USE OF:

> SPLAYED NOZZLES
> ANNULAR SEGMENTS
> OTHER NOZZLE SHAPES

3. COMPLETE LAYOUTS TO MATCH MOTORS AND IMPROVED COLLECTOR/NOZZLE UNIT.

4. PREPARE COMPARISON MATRIX.

5. COMPLETE FINAL REPORT.

6. MAKE FINAL TECHNICAL PRESENTATION.

EFFECT OF ANGLED WATERJET NOZZLES

- ■ THRUST LOSS, LBS.   ◆ LIFT GAIN, LBS.
- ○ LIFT/DRAG X 10
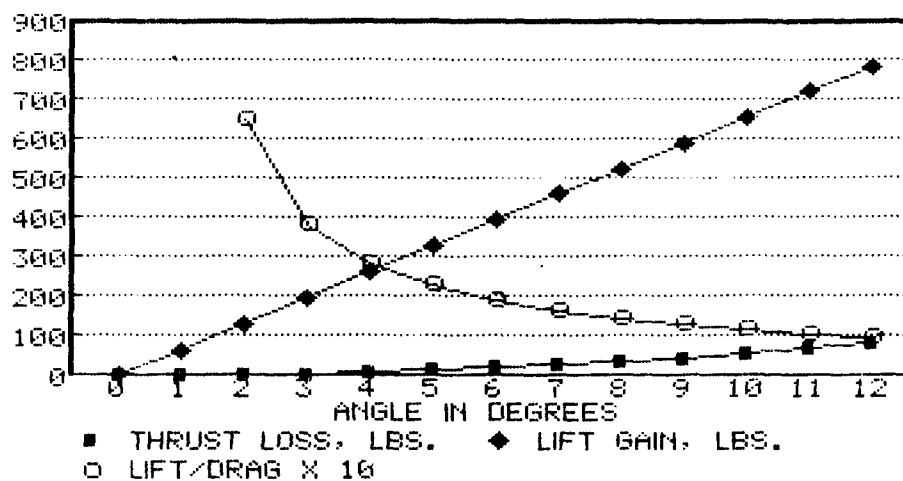
CLEARANCE GAIN FROM ANGLED NOZZLES
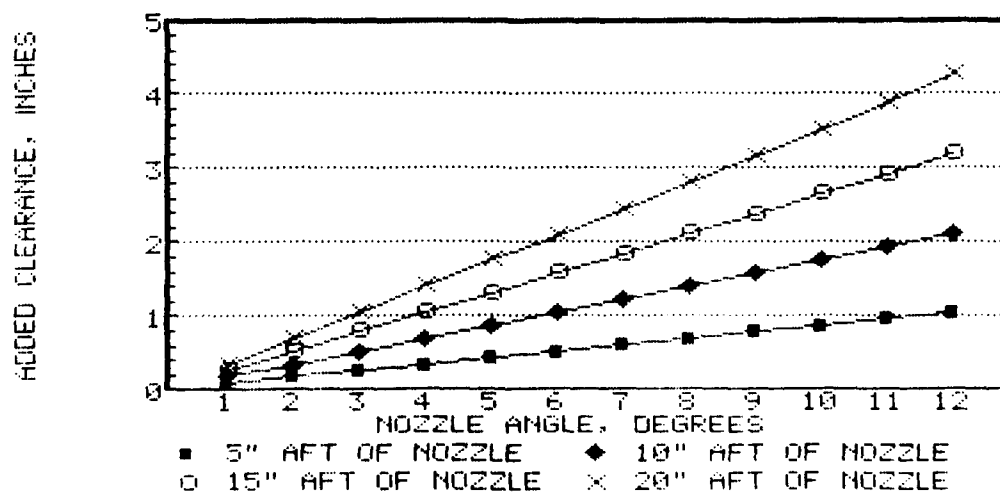
- ■ 5" AFT OF NOZZLE   ◆ 10" AFT OF NOZZLE
- ○ 15" AFT OF NOZZLE   ✕ 20" AFT OF NOZZLE

| HPM | # INLET LOCATION |

EFFECT OF CONVENTIONAL FORWARD WATERJET INLET ON THE LIFT COEFFICIENT OF A HYDRO-HYDRODYNAMIC PLANING SURFACE:

Data: Water Jet Propulsion – Competition for Propellers? (SAE Paper 740283) By Ralph Lambrecht, Outboard Marine

Analysis: Hydrodynamic Design of Planing Hulls By Dr. Dan Savitsky, Stevens Institute

$$C_{L\beta} = \triangle / (1/2 * \rho * V^2 * b^2)$$

$C_{L\beta}$ = Lift Coefficient

$\triangle$ = Load on water $\qquad$ V = Velocity FPS

ρ = Water mass density $\quad$ b = Beam, ft.

| HPM | # INLET LOCATION |

EFFECT OF CONVENTIONAL FORWARD WATERJET INLET ON THE LIFT COEFFICIENT OF A HYDRO-HYDRODYNAMIC PLANING SURFACE:

Value	Jet Boat	Prop Boat
$\triangle$	3140 lbs.	3140 lbs.
ρ	1.938	1.938
V	38.13 (26 MPH)	30.80 (21 MPH)
b	7.0 ft.	7.0 ft.
$C_{L\beta}$	0.045	0.070

HPM — INLET LOCATION

EFFECT OF CONVENTIONAL FORWARD WATERJET INLET ON LIFT:

1. The forward inlet diverts a layer of water about one foot thick from under the transom flap at 18 MPH.

2. A transom flap with a 6 foot span, 4 foot chord and 16.3 degree deflection diverts the same amount of water.

3. Dr. Savitsky's equation for flap lift is:

   $$f = 0.046 * Lf * \delta * \sigma * b * (p/2 * v^2)$$

4. This equation gives a lift value for a typical AAAV transom flap of <u>12,500</u> pounds.

HPM — THRUST PERFORMANCE

1. The reflex jet thrust performance is comparable to the DTRC waterjet.

2. The DTRC waterjet thrust performance is very good, therefor futher thrust gains will be limited.

3. The rearward location of the inlet of the reflex waterjet minimizes interference with the hull hydrodynamics.

4. With equal thrust, the reflex waterjet should provide better freerunning hull performance.

HPM   EXTRA STUDIES

DESIRABLE ADDITIONAL STUDIES:

1. Inlet location effects

2. Special weight saving materials

   Graphite/Epoxy composites
   Silicon Carbide/Aluminum composites

3. Waterjet/Flap integration

4. Motor/Gearing lubrication and cooling integration.

HPM   FINAL COMMENTS

1. REDUCTION OF WIDTH IS A CRITICAL GOAL.

2. THE CONCEPT OFFERS ADVANTAGES IN:

   LENGTH
   WEIGHT
   MAINTAINABILITY
   SYSTEM PERFORMANCE

3. PROGRAM RISK HAS BEEN MINIMIZED BY USING PROVEN DESIGN FACTORS FROM PREVIOUS JETS THAT HAVE BEEN EXTENSIVELY TESTED. THE EXPERIENCE FROM THE PREVIOUS EFFORTS PROVIDES THE DATA FRQUENTLY OBTAINED BY HALF SCALE MODEL TESTS.

APPENDIX C

REFLEX JET FINAL PRESENTATION

by

Waldo E. Rodler
1488 Cherry Garden Lane
San Jose, CA 95125

Presented at
Quantico, VA

April 26, 1990

FINAL REPORT PRESENTATION
DTRC CONTRACT N00167-90-0058

INTEGRAL
ELECTRIC MOTOR/WATERJET

QUANTICO, VA
APRIL 26, 1991

BY:

WALDO E. RODLER

HIGH PERFORMANCE
MARINE PRODUCTS
SPINGFIELD, MO

HPM	REFLEX WATERJET SYSTEM

1. THIS HAS BEEN A DESIGN STUDY CONTRACT

2. THE KICKOFF MEETING WAS HELD OCTOBER 10, 1990 IN SPRINGFIELD, MO

3. THE MID PROGRAM REVIEW WAS HELD JANUARY 29, 1991 AT DTRC, BETHESDA, MD

4. THE WATERJET CONCEPT IS BASED ON PRIOR DESIGNS FOR PLEASURE BOATS.

5. THE CONCEPT WAS OPTIMIZED FOR THE AAAV APPLICATION

HPM	REFLEX WATERJET SYSTEM

1. CONCEPT FEATURES:

   REAR INLET LOCATION

   ELBOW INLET

   MIXED FLOW IMPELLER

   MULTIPLE NOZZLES

2. CONCEPT ADVANTAGES

   SHORT LENGTH

   EFFECTIVE INLET

   SIMPLE, EFFICIENT IMPELLER

   LIGHT WEIGHT

   GOOD MAINTAINABILITY

   AFFORDABLE COST

   LOW PROGRAM RISK

HPM	REFLEX WATERJET SYSTEM

1. DESIGN IS BASED ON EXPERIENCE WITH PRIOR RECREATIONAL JETS AND EXTENSIVE EXPERIENCE WITH MILITARY VEHICLES

2. RECREATIONAL JETS:
   * SERIES #1 PROTOTYPES (3)
   * SERIES #2 PROTOTYPES (3)
   * SERIES #2 PRODUCTION (50)

3. MILITARY VEHICLES:
   * HIGH HERMAN (MINE ROLLER)
   * GALLOPING GHOST (RADIO CONTROLLED MINE ROLLER)
   * M113 (PRODUCT IMPROVEMENT)
   * XM474-E2 PERSHING MISSILE CARRIER
   * M548 AMPHIBIOUS CARGO CARRIER
   * XM808 LOCKHEED TWISTER
   * LVA, FMC STUDY
   * LVT(X), FMC STUDY
   * AAAV, EARLY FMC STUDIES

REFLEX WATERJET SYSTEM

HPM

7.34" JET

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REFLEX WATERJET SYSTEM

HPM

AAAV JET

JET

JET

14 STEP

24 OVER ALL

TRANSOM FLAP

60

21
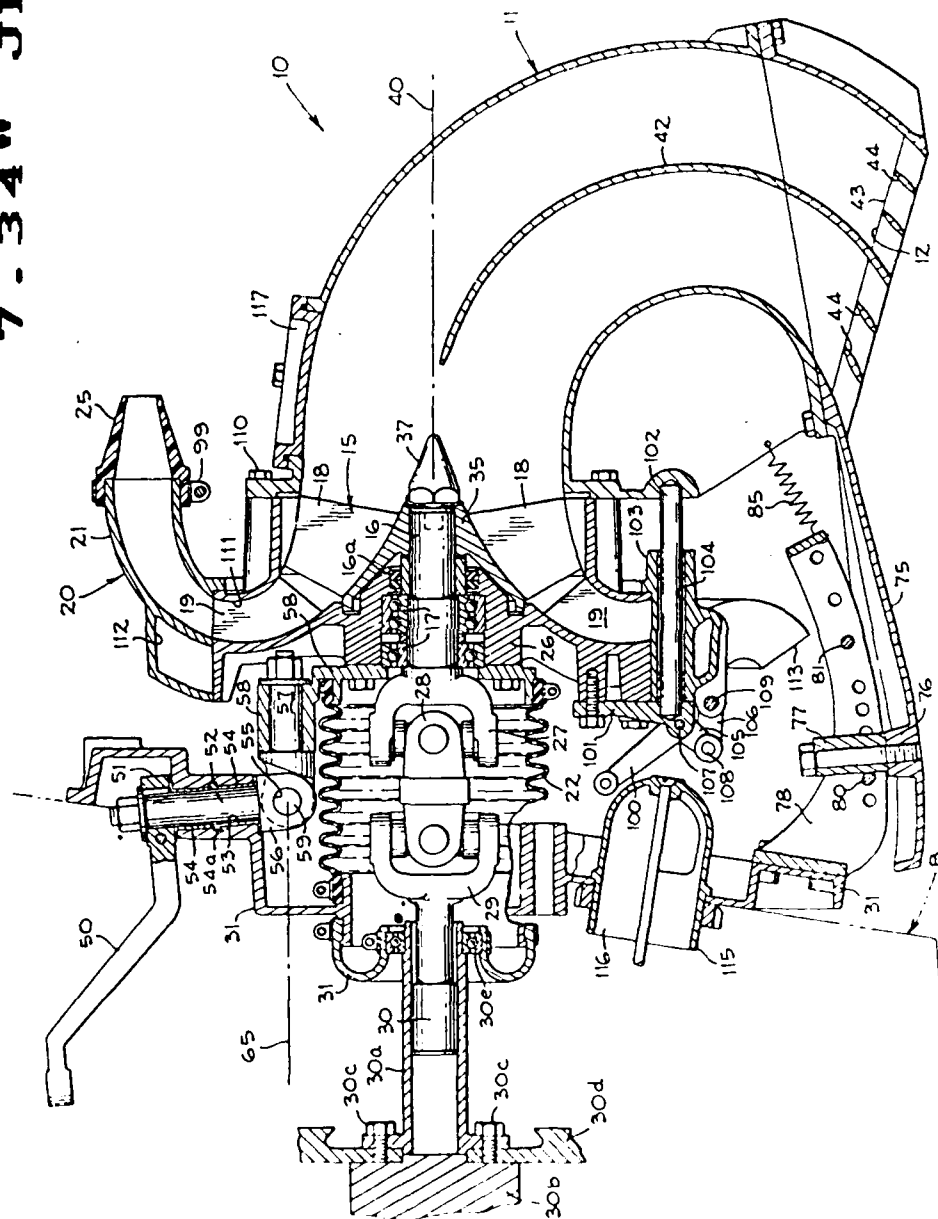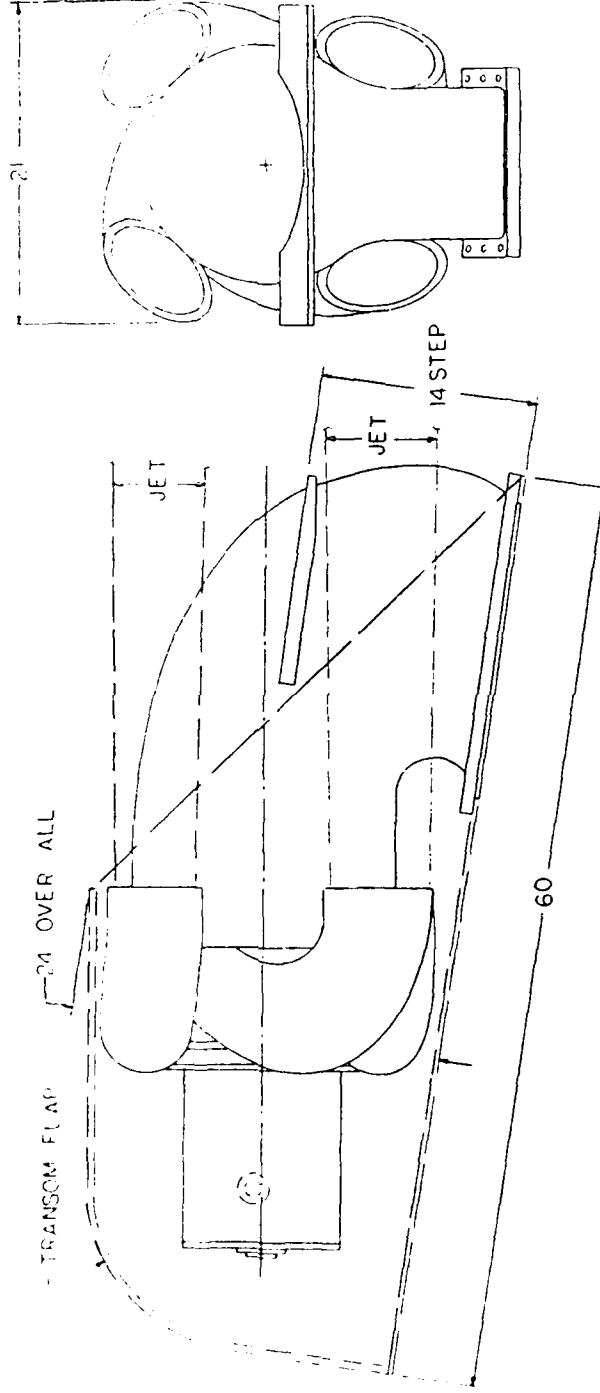
| HPM | REFLEX WATERJET SYSTEM |

PROCEDURES

PERFORMANCE OPTIMIZATION WAS MADE BY USE OF "JETOPT9D" PROGRAM

1. INLET DRAG IS BASED ON CAPTURE AREA, HULL SPEED & AN EXPERIMENTAL COEFFICIENT

2. RAM HEAD RECOVERY IS BASED ON HULL SPEED AND AN EXPERIMENTAL COEFFICIENT

3. INLET LOSS IS BASED ON CURVATURE AND CONVERGENCE

4. IMPELLER EFFICIENCY IS BASED ON TIP SPEED, DIAMETER, CAVITATION FACTOR, FLOW AND PRESSURE

5. STATOR & NOZZLE LOSSES ARE BASED ON GEOMETRY AND EXPERIMENTAL COEFFICIENTS

HPM	REFLEX WATERJET SYSTEM

PROCEDURES

USE OF "JETOPT9D" PROGRAM

ADDITIONAL FACTORS EVALUATED
BY THE PROGRAM:

1. SIZE OF THE WATERJET

2. INTERNAL FLOW VELOCITIES

3. ANTICIPATED SURFACE FINISHES

THE PROGRAM ITERATES THROUGH
MANY COMBINATIONS OF THESE
INTERRELATED FACTORS TO PROVIDE
OPTIMIZED PERFORMANCE

HPM	REFLEX WATERJET SYSTEM

PROCEDURES:

IMPELLER DESIGN IS BASED ON
AUTOMOTIVE TORQUE CONVERTER
DESIGN TECHNOLOGY TO PROVIDE:

1. HIGH RESISTANCE TO
   CAVITATION

2. HIGH EFFICIENCY

3. SIMPLE CONTOURS THAT FAVOR
   ECONOMICAL FABRICATION

HPM	REFLEX WATERJET SYSTEM

PROCEDURES:

INLET CAPTURE AREA DESIGN

1. BASED ON EXPERIMENTAL DEVELOPMENT AND TEST FOR 7.34" WATERJET

2. DESIGN HAS DEMONSTRATED:

   * GOOD RAM HEAD RECOVERY

   * LOW DRAG COEFFICIENT

   * FREEDOM FROM VENTILATION

   * PROTECTION FROM ENTRANCE OF FOREIGN ITEMS

HPM	REFLEX WATERJET SYSTEM

PROCEDURES:

INLET ELBOW DESIGN

1. IS BASED ON PRIOR SUCCESSFUL DESIGNS

2. RETAINS PROVEN:

   * VELOCITIES

   * RADIUS OF CURVATURE

3. USES CONVERGENT FLOW

   * MINIMIZES LOSSES

   * PROVIDES FAVORABLE VELOCITY DISTRIBUTION AT DISCHARGE

HPM	REFLEX WATERJET SYSTEM

PROCEDURES :

NOZZLE DESIGN

1. PASSAGES ALIGNED WITH THE
   IMPELLER FLOW

2. CONTINUES ANGULAR ACCELER-
   ATION STARTED BY IMPELLER

3. CONTINUES PROGRESSIVE
   ACCELERATION OF FLUID

4. DISCHARGE SIZE DETERMINED
   BY PERFORMANCE OPTIMIZATION

| HPM | REFLEX WATERJET SYSTEM |

RESULTS:

1. A LOW RISK WATERJET CONCEPT
   TO PROVIDE THE REQUIRED
   AAAV THRUST

2. ADDITIONAL ADVANTAGES:

   * SHORT LENGTH

   * LOW WEIGHT

   * LOW COST

   * SIMPLE MAINTENANCE

   * IMPROVED HULL PERFORMANCE

HPM	REFLEX WATERJET SYSTEM

RESULTS:

SHORT LENGTH IS ACHIEVED BY
THESE FEATURES:

1. THE INLET CAPTURE AREA IS
   BELOW THE MAIN WATERJET
   BODY, RATHER THAN AHEAD OF
   IT

2. THE NOZZLES ARE ALONG THE
   SIDE OF THE PUMP, RATHER
   THAN BEHIND IT

3. A LARGER DIAMETER AND
   CORREPONDINGLY SHORTER
   MOTOR CAN BE USED BECAUSE
   IT IS NOT IN THE WATER FLOW

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HPM	REFLEX WATERJET SYSTEM

RESULTS:

LOW WEIGHT

1. THE ESTIMATED WEIGHT, BASED ON ACTUAL WEIGHTS OF 7.34" DESIGN IS 442 POUNDS (WITH INTAKE, WITHOUT MOTOR)

2. MOTOR WEIGHT SHOULD BE ABOUT 109 POUNDS (MEDIAN OF ESTIMATES BY THREE MOTOR SOURCES)

3. TOTAL SYSTEM WEIGHT IS ESTIMATED TO BE 551 POUNDS

4. WEIGHT IS BASED ON STANDARD ALUMINUM CONSTRUCTION

5. COMPOSITES AND ADVANCED MATERIALS CAN SAVE WEIGHT AT ADDED COST

HPM	REFLEX WATERJET SYSTEM

RESULTS:

LOW COST

1. PRIOR TESTS HAVE SHOWN THAT A SIMPLE ALUMINUM IMPELLER WILL MEET PERFORMANCE AND LIFE REQUIREMENTS.

2. STANDARD ALUMINUM CONSTRUCTION MINIMIZES COST.

3. SIMPLE MOTOR INTERFACE AND AMPLE CLEARANCE FOR DIFFERENT DIAMETERS AND LENGTHS ASSURES ADAPTABILITY OF MULTIPLE SOURCE MOTORS.

HPM	REFLEX WATERJET SYSTEM

RESULTS:

SIMPLIFIED MAINTENANCE

1. MOTOR, REDUCTION GEAR AND IMPELLER FORM A SINGE SEALED REPLACEMENT UNIT

2. MOUNTING BOLTS AND ELECTRIC CONNECTIONS ARE EASILY ACCESIBLE

HPM	REFLEX WATERJET SYSTEM

RESULTS

IMPROVED HULL PERFORMANCE

1. THE FORWARD INLET LOCATION OF A CONVENTIONAL WATERJET MAY SIGNIFICANTLY EFFECT HULL PERFORMANCE.

2. OUTBOARD MARINE CORP. DATA PUBLISHED IN SAE PAPER 740283 APPEARS TO SHOW THAT A FORWARD INLET LOWERED A HULL LIFT COEFFICIENT FROM 0.070 TO 0.045

3. TESTS OF REFLEX JET POWERED BOATS PERFORMED BETTER THAN CAN BE EXPLAINED BY JET THRUST PERFORMANCE

(CONTINUED)

018

HPM	REFLEX WATERJET SYSTEM

RESULTS

IMPROVED HULL PERFORMANCE (CONTINUED)

4. A TRANSOM FLAP THAT DEFLECTS THE AS MUCH WATER AS IS DIVERTED BY THE FORWARD WATERJET INLET, WOULD YIELD ABOUT 12,500 POUNDS OF LIFT.

5. MORE STUDY AND TESTS ARE NEEDED TO DETERMINE THE EFFECT OF INLET LOCATION ON HULL PERFORMANCE

| HPM | REFLEX WATERJET SYSTEM |

MINIMIZING PROGRAM RISK

PROGRAM RISK HAS BEEN MINIMIZED BY:

1. BASING THE DESIGN ON A THOROUGHLY TESTED CONCEPT

2. BY RETAINING PROVEN DESIGN FACTORS:

   * WATER VELOCITY

   * PASSAGE CURVATURE

   * IMPELLER BLADE ANGLES

   * IMPELLER TIP SPEED

   * CONVERGENCE RATES

   * CAVITATION FACTORS

| HPM | REFLEX WATERJET SYSTEM |

MECHANICAL DESIGN FEATURES

1. GENERALLY FOLLOWS PRIOR SUCCESSFUL DESIGNS

2. ENTIRE WATERJET IS SUPPORTED BY THE INTAKE ELBOW

3. INTAKE ELBOW ISOLATES MOTOR AND PUMP FROM TRANSOM FLAP DEFLECTIONS

4. ISOLATION FROM DEFLECTION MINIMIZES REQUIRED TIP CLEARANCE

5. MINIMUM TIP CLEARANCE:

   * IMPROVES PUMP EFFICIENCY

   * EXTENDS SERVICE LIFE BEFORE TIP WEAR BECOMES EXCESSIVE

021

| HPM | REFLEX WATERJET SYSTEM |

MECHANICAL DESIGN FEATURES

1. MOTOR IS MOUNTED BY:

   * MOUNTING FACE
   * PILOT RING
   * BOLT CIRCLE

2. MOUNTING ARRANGEMENT IS
   WELL PROVEN IN AIRCRAFT
   FOR 12,000 RPM ALTERNATORS
   AND PUMPS

3. ELECTRICAL CONNECTIONS ARE
   READILY ACCESSIBLE

4. INSTALLATION AND SEALING
   ARE SIMPLIFIED BY THIS
   ACCESSIBILITY

5. LACK OF CRITICAL DIAMETER
   AND LENGTH CONSTRAINTS
   PERMITS ALTERNATE MOTOR
   DESIGNS AND SOURCES.

022

HPM	REFLEX WATERJET SYSTEM

MECHANICAL DESIGN FEATURES

1. IMPELLER IS MOUNTED TO STAR REDUCTION GEAR STATOR

2. WIDE BEARING SPREAD ASSURES RIGIDITY FOR MINIMUM TIP CLEARANCE

3. SINGLE REDUCTION STAGE PROVIDES NEEDED RATIO

4. RING GEAR IS SPLINED TO IMPELLER AND RETAINED BY SNAP RING

5. GEAR STRESS, BEARING LOADS AND SEAL RUBBING VELOCITY HAVE BEEN CHECKED AND SUITABLE SOURCES LOCATED

6. FEASIBILITY IS ASSURED, BUT OPTIMIZATION IS REQUIRED IN PHASE 2

023

HPM	REFLEX WATERJET SYSTEM

INTEGRATION WITH VEHICLE

1. THE WATERJET CAN BE MOUNTED DIRECTLY TO TRANSOM FLAP

2. THERE ARE TRADE OFFS BETWEEN JET LENGTH, WIDTH AND HEIGHT

3. PHASE 2 COORDINATION WITH VEHICLE MANUFACTURER COULD OPTIMIZE TRANSOM FLAP SYSTEM DESIGN

024

HPM	REFLEX WATERJET SYSTEM

INTEGRATION WITH VEHICLE,

WIDE "T" FLAP OPTION

1. "T" FLAP MOUNTS TO HULL WITH WITH NARROW SECTION NEAR HULL TO CLEAR TRACKS AND WIDE REAR AREA FOR JETS

2. WIDE JET MOUNTING AREA WILL PERMIT:

   * ENTRY AREA BETWEEN JETS TO REDUCE EXPOSURE OF TROOPS ENTERING & LEAVING VEHICLE

   * PROVIDES PERSONNEL DOOR IN RAMP SO TROOPS CAN ENTER WITHOUT LOWERING FLAP

3. REQUIRES REFLEX TYPE MANEUVERING JETS SO THEIR DISCHARGE CLEARS TRANSOM FLAP

025

HPM | REFLEX WATERJET SYSTEM

"T" FLAP CONCEPT:

JET

REFLEX MANEUVER JET

32 X46 DOOR

36 WALKWAY

132

40

60

DEPLOYED FLAP, PLAN VIEW

026
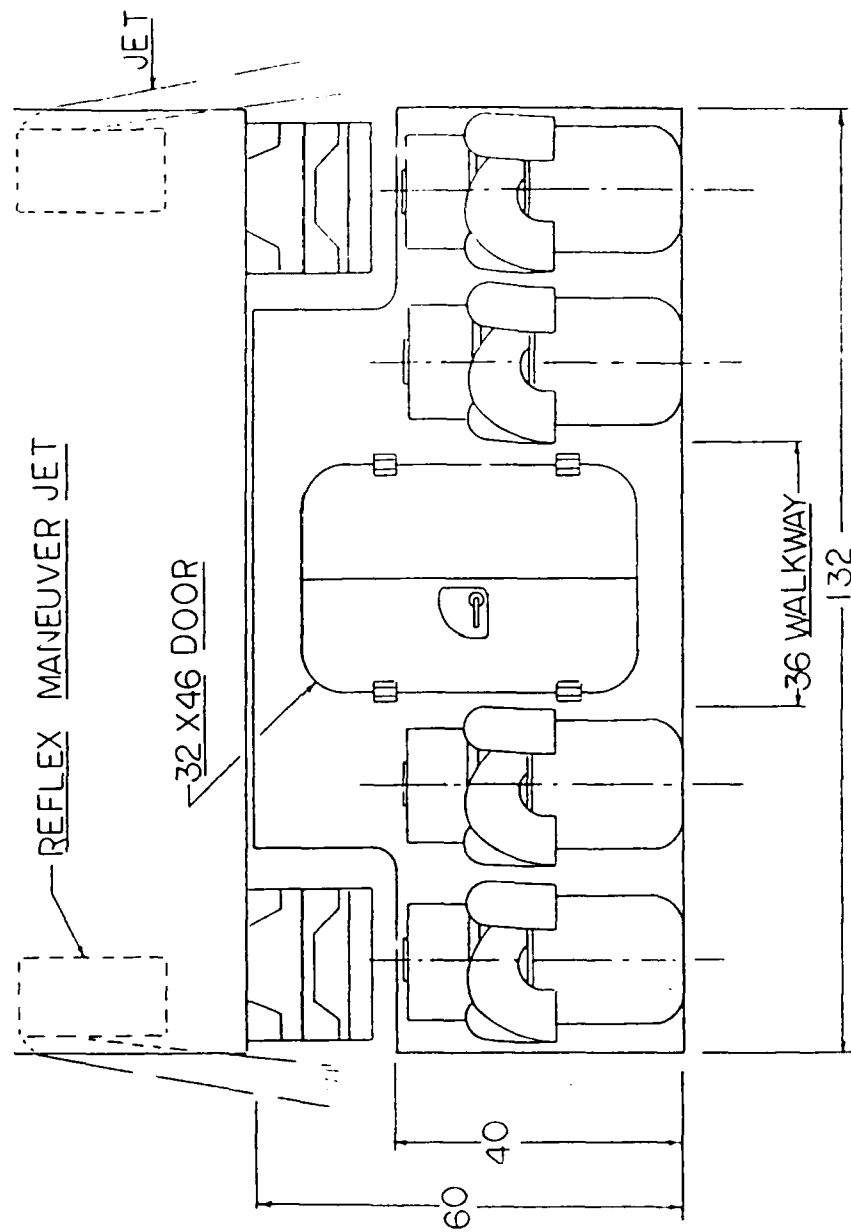
HPM	REFLEX WATERJET SYSTEM

REFLEX MANEUVERING JETS

1. SIMILAR TO HPM RECREATIONAL JET, EXCEPT NOZZLES TURNED 90 DEGREES

2. DISCHARGE ANGLED OUTWARD APPROXIMATELY 7 DEGREES TO CLEAR TRANSOM FLAP

3. THRUST LOSS FROM THE 7 DEGREE ANGLE IS LESS THAN 1 PERCENT

4. INLET BEHIND TRACK AVOIDS INTAKE RESTRICTION TO IMPROVE THRUST

5. STEERING BY DEFLECTOR AND REVERSE DISCHARGE PASSAGE

027

HPM | REFLEX WATERJET SYSTEM

HPM RECREATIONAL REFLEX JET:

028
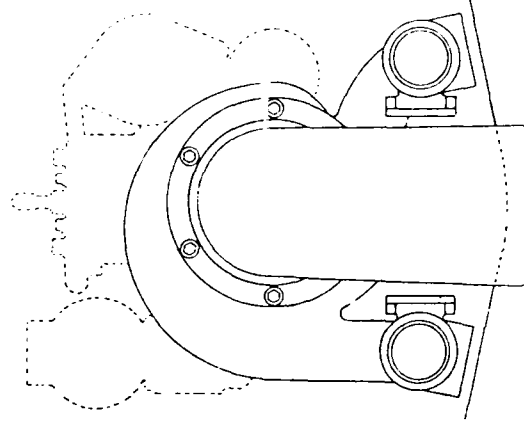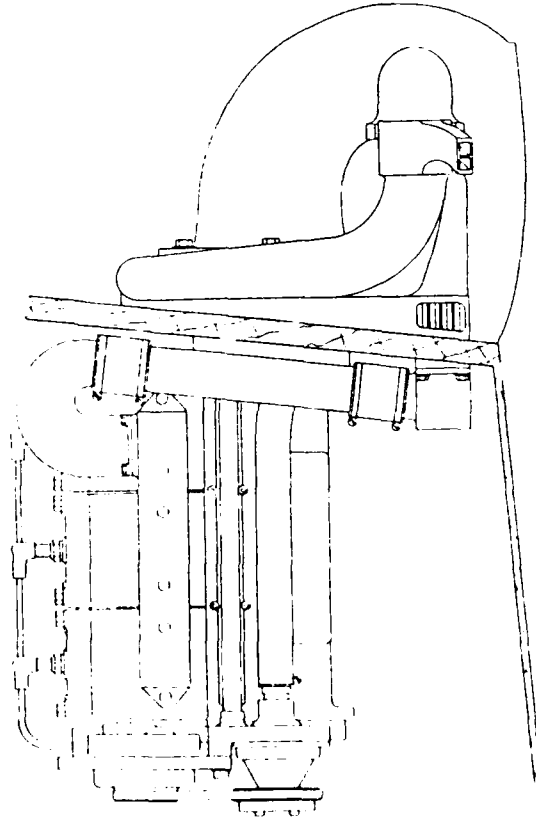
HPM	REFLEX WATERJET SYSTEM

STEERING OPTIONS:

1. DIFFERENTIAL MOTOR SPEEDS

   * SIMPLE MECHANICAL DESIGN
   * ADDED ELECTRIC CONTROL
     REQUIREMENT
   * POTENTIAL FOR CAVITATION
     AT LOW HULL SPEEDS
   * MOST EFFECTIVE WITH WIDE
     JET SPACING

2. INDIVIDUAL NOZZLE DEFLECTORS

   * COMPLEX MECHANICAL DESIGN
     WITH MANY COMPONENTS
   * NO ELECTRIC CONTROL CHANGE
   * NO CAVITATION PROBLEMS

3. JETS MOUNTED ON TRUNNIONS

   * PROVEN EFFECTIVE ON PRIOR
     REFLEX JETS
   * SIMPLE MECHANICAL DESIGN
   * MINOR LOSS OF FLAP AREA

HPM | REFLEX WATERJET SYSTEM

TRUNION MOUNTED JET STEERING:

TRANSOM FLAP

24 OVER ALL

MOUNTING TRUNNION

JET

JET

14 STEP

21

60

030
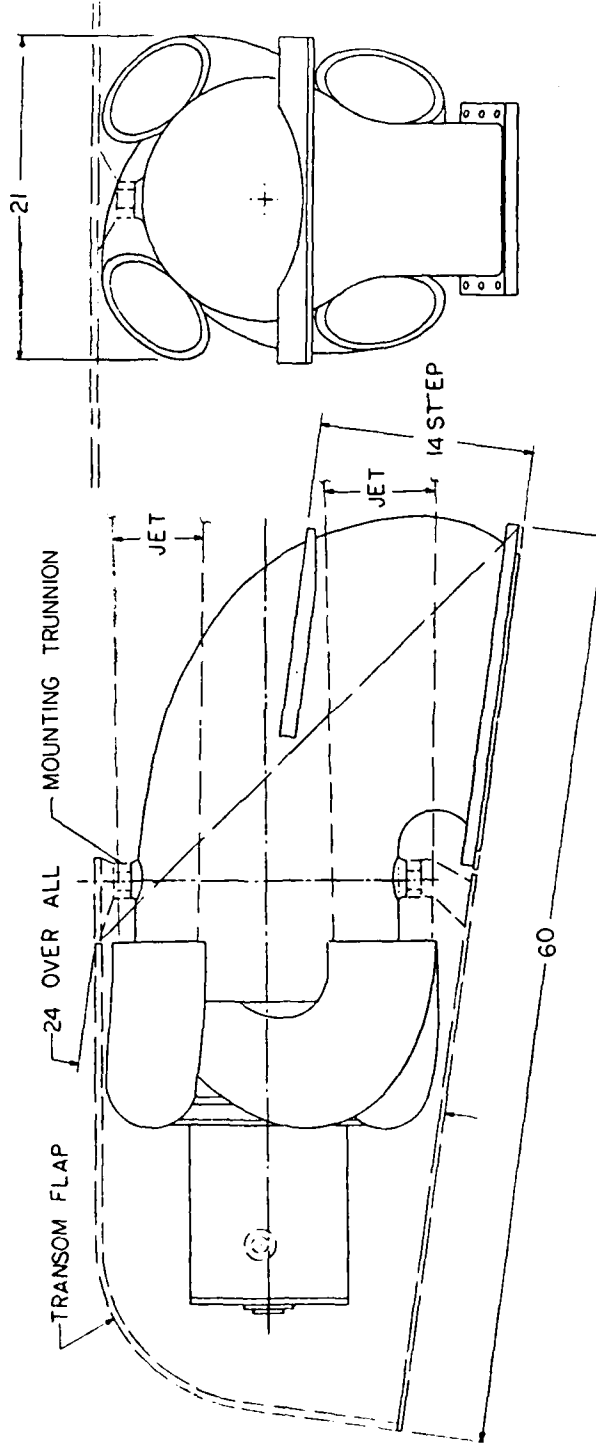
HPM	REFLEX WATERJET SYSTEM

CONCLUSIONS FOR THE AAAV:

THE REFLEX WATERJET:

* MEETS PERFORMANCE GOAL

* FITS THE VEHICLE SYSTEM

* OFFERS GOOD ALTERNATIVES

* IS LIGHT WEIGHT

* IS MAINTAINABLE

* IS AFFORDABLE

* IS A LOW RISK DEVELOPMENT

031

APPENDIX D

SAMPLE CALCULATIONS

By: Waldo E. Rodler
1488 Cherry Garden Lane
San Jose, CA 19125

1. THE ANALYSIS STARTED WITH A SENSITIVITY STUDY TO DETERMINE THE OPTIMUM VALUES FOR THIS JET. A MATRIX OF RUNS OF THE "JETOPTQ" PROGRAM WAS MADE, PROGRESSIVELY CHANGING SIZE, RPM, EFFECT OF LIFT AND CAVITATION CHARACTERISTICS. A TYPICAL SAMPLE PRINTOUT IS SHOWN ON PAGE 2.

2. THE RESULTS OF THIS MATRIX OF RUNS WAS PLOTTED FOR EVALUATION. THESE DATA AND THEIR PLOTS ARE SHOWN AS FOLLOWS:

	Page
EFFECT OF SIZE ON THRUST + WEIGHT	3
EFFECT OF RPM ON THRUST + SPECIFIC SPEEDS	4
EFFECT OF LIFT ON THRUST	5
CAVITATION MARGIN Vs 16 MPH THRUST	6
CAVITATION MARGIN Vs 18 MPH THRUST	7

3. THE RESULTS WERE COMBINED IN A SERIES OF RUNS. RUN 901031.5 PRODUCED EXCELLENT PERFORMANCE. IT REPRESENTS THE BEST THAT CAN REASONABLY BE EXPECTED FROM A 16.1" REFLEX JET INSTALLED IN THE AAAV. RESULTS ARE TABULATED AND PLOTTED ON PAGE 8.

4. CONSIDERABLE CONCERN HAS BEEN EXPRESSED ABOUT THE POTENTIAL LOSSES FROM THE CURVED PASSAGES IN THE REFLEX JET. TO PROVIDE A DEMON-STRATION THAT CURVED PASSAGES CAN BE EFFICIENT, A SAMPLE TORQUE CONVERTER ANALYSIS WAS MADE USING THE TC-4G PROGRAM. THIS ANALYSIS HAS BEEN CONFIRMED BY TESTS OF CONVERTERS BUILT IN THE US AND JAPAN. THE RESULTS OF THE PROGRAM RUN 900912 ARE SHOWN ON PAGE 9 AND PLOTTED ON PAGE 10. THESE RESULTS SHOW HIGH EFFICIENCY IN SPITE OF HIGHLY CURVED TORUS FLOW PATH.

```
************************************************************************
***************** WATERJET OPTIMIZATION PROGRAM JETOPT9 ****************
************************************************************************
```

FILE CODE: JETOPT9D   REVISION 10/7/1986
NOTE: THIS PROGRAM IS PROPRIETARY DATA OF W. E. RODLER AND IS NOT TO BE USED OR
      COPIED WITHOUT HIS EXPRESS WRITTEN PERMISSION
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======================================================================
```

DATA INPUT:
RUN DATE:900910   IMPELLER D., IN: 16   NET SHAFT HP---: 397
DIFFUSION Kdf-: .85   DEGREES INLET--: 165   TURNS IN-------: 1
CAV. LIMIT MPH: 8   INLET LIFT, FT-: -2   VEL. CONV. Kv--: .6500001
TIP SPEED, FPS: 125   INLET DRAG Cd--: .05   RAM RECOVERY Kr: .75
RUN NUMBER:---: 25   ACCURACY LEVEL-: 100
```
======================================================================
```
DESIGN POINT RESULTS:
            INLET VELOCITY, FEET PER SECOND..................... 34.25707
            INPUT SHAFT RPM.................................... 1790.495
            SUCTION SPECIFIC SPEED............................. 20413.38
            PUMP EFFICIENCY IN PER CENT........................ 84.51998
            PUMP PRESSURE, PSI................................. 29.77992
            PUMP SPECIFIC SPEED............................... 10426.17
            NOZZLE AREA IN SQUARE INCHES...................... 97.42499
            JET SPEED IN MPH RELATIVE TO HULL................. 43.37734
```
======================================================================
```
SPEED VS. THRUST:

SPEED, MPH	THRUST,LBS	FLOW, GPM	IDEAL EFF%	PROP. EFF%	EFFEC. HP
0.00	5333.70	19316.77	0.00	0.00	0.00
2.50	5038.06	19370.02	10.87	8.46	33.59
5.00	4748.34	19370.02	20.62	15.95	63.31
7.50	4475.74	19477.42	29.28	22.55	89.51
10.00	4211.35	19586.01	37.05	28.29	112.30
12.50	3955.13	19695.82	44.07	33.21	131.84
15.00	3708.07	19862.87	50.34	37.36	148.32
17.50	3467.73	20032.77	56.02	40.76	161.83
20.00	3233.88	20263.88	61.07	43.44	172.47
22.50	3005.30	20500.39	65.66	45.42	180.32
25.00	2780.56	20803.90	69.72	46.69	185.37
27.50	2561.30	21053.26	73.56	47.31	187.83
30.00	2341.94	21438.70	76.79	47.19	187.36
32.50	2127.46	21770.86	79.87	46.44	184.38
35.00	1912.28	22183.29	82.54	44.96	178.48
37.50	1702.39	22539.10	85.12	42.88	170.24
40.00	1489.83	22981.45	87.34	40.03	158.92
42.50	1277.61	23441.51	89.35	36.47	144.80
45.00	1059.22	24002.07	91.01	32.02	127.11
47.50	845.43	24504.35	92.66	26.97	107.09
50.00	630.34	25028.09	94.17	21.17	84.05
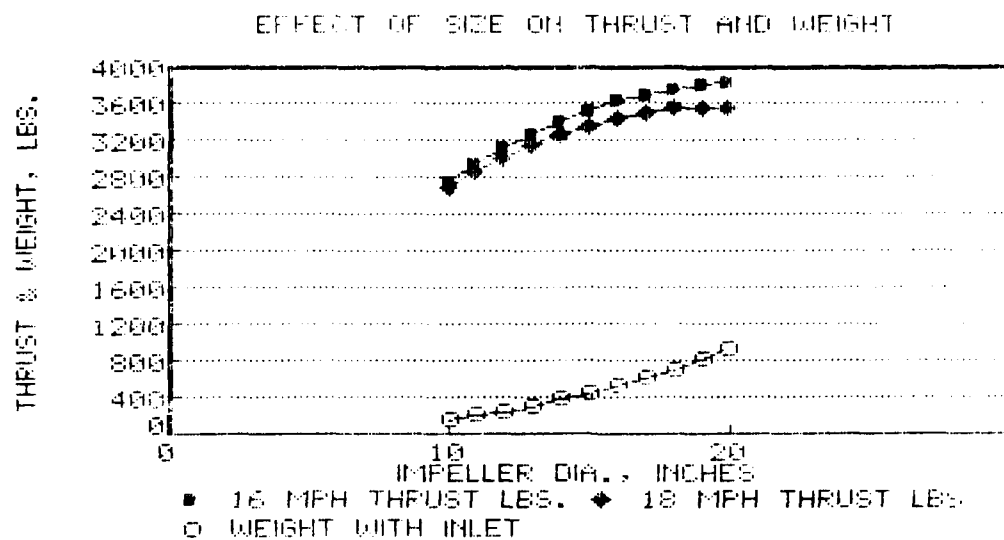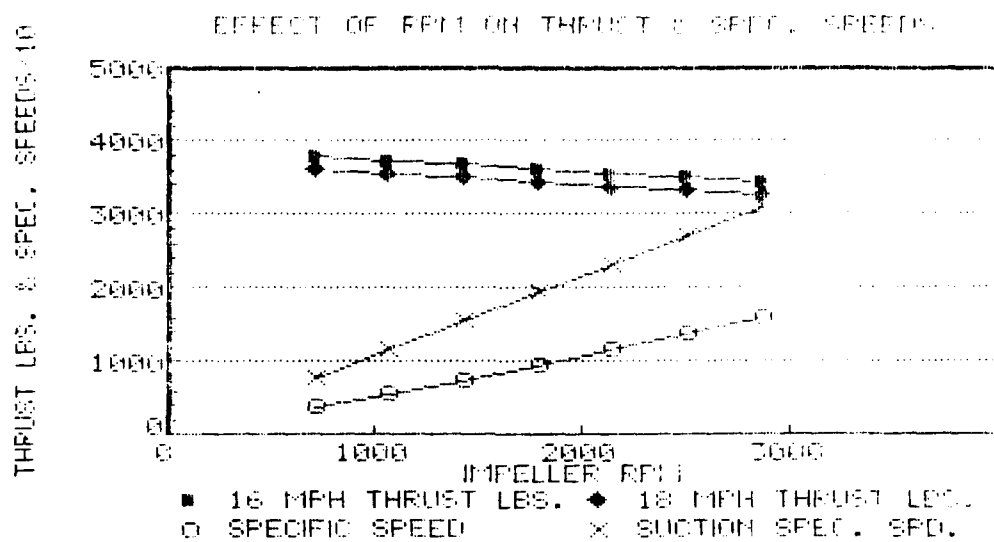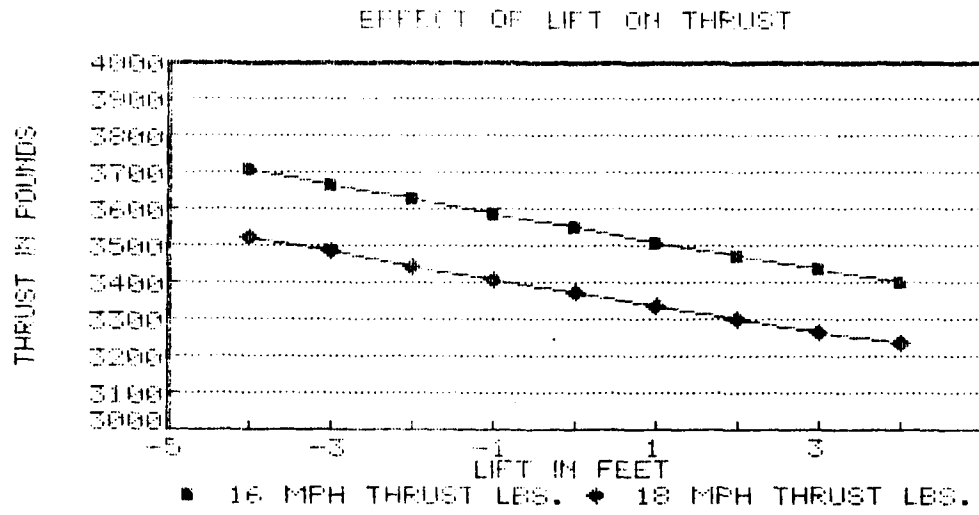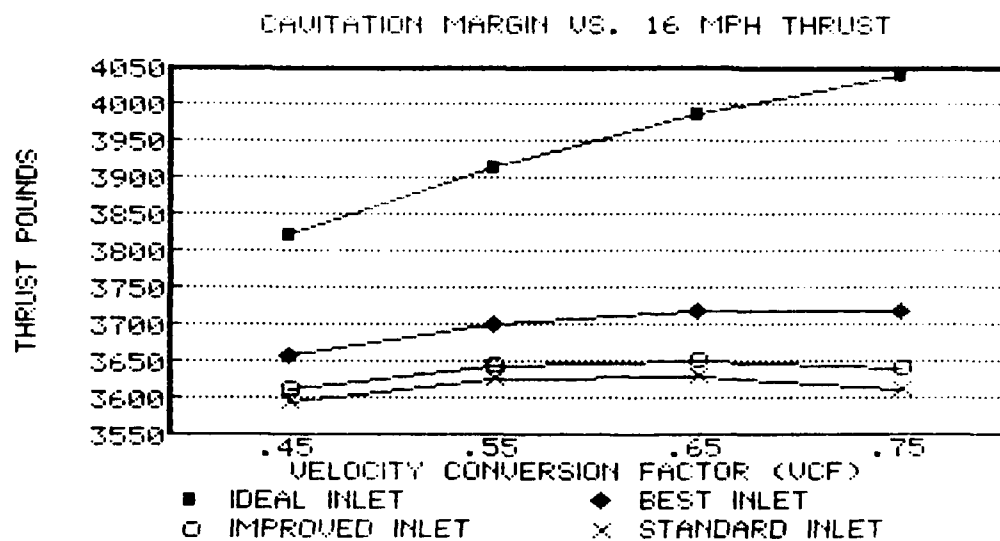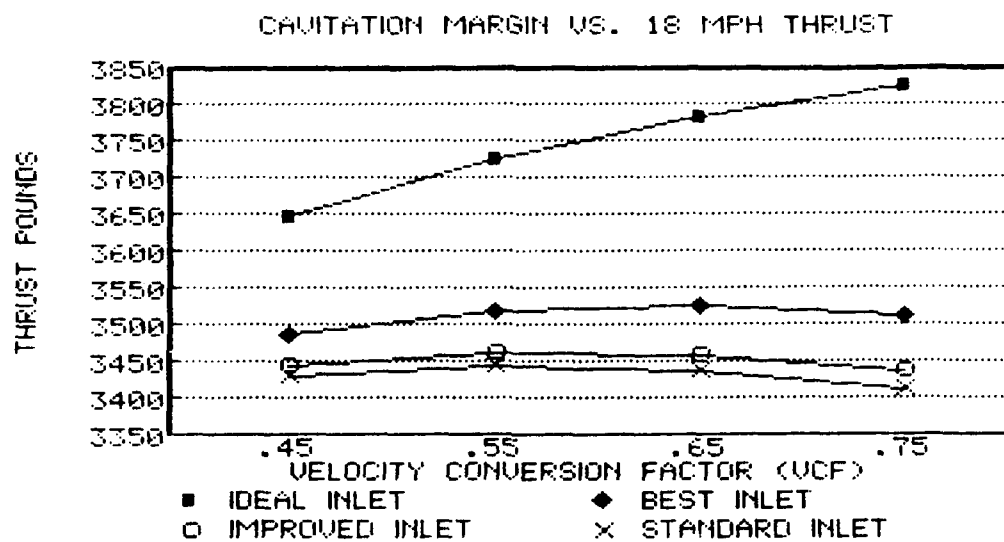
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======================================================================
```
FLOW ITERATIONS- 669   PUMP EFF. ITERATIONS= 557
```

EFFECT OF SIZE ON THRUST AND WEIGHT



| X Data | 16 MPH THRUST LBS. | 18 MPH THRUST LBS | WEIGHT WITH INLET |
|--------|--------------------|--------------------|--------------------|
| 10 | 2767 | 2690 | 162 |
| 11 | 2954 | 2862 | 206 |
| 12 | 3124 | 3017 | 256 |
| 13 | 3277 | 3154 | 313 |
| 14 | 3412 | 3271 | 377 |
| 15 | 3530 | 3370 | 448 |
| 16 | 3629 | 3449 | 526 |
| 17 | 3709 | 3509 | 612 |
| 18 | 3769 | 3548 | 706 |
| 19 | 3811 | 3567 | 809 |
| 20 | 3830 | 3563 | 919 |

EFFECT OF RPM ON THRUST & SPEC. SPEEDS

Legend:
- ■ 16 MPH THRUST LBS.
- ◆ 18 MPH THRUST LBS.
- ○ SPECIFIC SPEED
- ✕ SUCTION SPEC. SPD.

| X Data | 16 MPH THRUST LBS. | 18 MPH THRUST LBS. | SPECIFIC SPEED | SUCTION SPEC. SPD. |
|--------|--------------------|--------------------|----------------|--------------------|
| 716    | 3796               | 3616               | 360.60         | 771.90             |
| 1074   | 3741               | 3561               | 549            | 1157.80            |
| 1432   | 3686               | 3506               | 743.30         | 1543.80            |
| 1790   | 3629               | 3449               | 943.90         | 1929.80            |
| 2148   | 3570               | 3391               | 1151.30        | 2315.70            |
| 2507   | 3511               | 3332               | 1366.10        | 2701.70            |
| 2865   | 3449               | 3271               | 1588.80        | 3087.70            |

## EFFECT OF LIFT ON THRUST



| X Data | 16 MPH THRUST LBS. | 18 MPH THRUST LBS. |
|--------|--------------------|--------------------|
| -4 | 3709 | 3525 |
| -3 | 3668 | 3486 |
| -2 | 3629 | 3449 |
| -1 | 3589 | 3412 |
| 0 | 3551 | 3376 |
| 1 | 3512 | 3340 |
| 2 | 3475 | 3304 |
| 3 | 3438 | 3271 |
| 4 | 3402 | 3237 |

CAVITATION MARGIN VS. 16 MPH THRUST



| X Data | IDEAL INLET | BEST INLET | IMPROVED INLET | STANDARD INLET |
|--------|-------------|------------|----------------|----------------|
| .45 | 3823 | 3659 | 3612 | 3596 |
| .55 | 3916 | 3700 | 3644 | 3625 |
| .65 | 3987 | 3718 | 3651 | 3629 |
| .75 | 4042 | 3718 | 3640 | 3612 |

## CAVITATION MARGIN VS. 18 MPH THRUST



| X Data | IDEAL INLET | BEST INLET | IMPROVED INLET | STANDARD INLET |
|--------|-------------|------------|----------------|----------------|
| .45 | 3649 | 3489 | 3446 | 3431 |
| .55 | 3726 | 3519 | 3464 | 3446 |
| .65 | 3785 | 3525 | 3460 | 3438 |
| .75 | 3826 | 3513 | 3439 | 3412 |

AAAV WATERJET PERFORMANCE RUN 901031.5



HULL SPEED IN MPH
■ THRUST IN POUNDS     ◆ FLOW, GPM/10
○ P. C. × 10,000

| X Data | THRUST IN POUNDS | FLOW, GPM/10 | P. C. × 10,000 |
|--------|------------------|--------------|-----------------|
| 0 | 5830.04 | 2095.80 | 0 |
| 2 | 5568.57 | 2095.80 | 742 |
| 4 | 5317.76 | 2098.70 | 1418 |
| 6 | 5076.61 | 2104.50 | 2031 |
| 8 | 4844.16 | 2113.20 | 2584 |
| 10 | 4617.56 | 2122.10 | 3078 |
| 12 | 4398.48 | 2133.90 | 3519 |
| 14 | 4184.62 | 2145.90 | 3906 |
| 16 | 3977.13 | 2161.20 | 4242 |
| 18 | 3775.20 | 2179.70 | 4530 |
| 20 | 3577.30 | 2198.60 | 4770 |
| 22 | 3383.85 | 2222.10 | 4963 |
| 24 | 3194.07 | 2247.20 | 5111 |
| 26 | 3007.02 | 2270.60 | 5212 |
| 28 | 2822.94 | 2298 | 5269 |
| 30 | 2641.02 | 2329.60 | 5282 |
| 32 | 2461.02 | 2362 | 5250. |
| 34 | 2282.74 | 2395.40 | 5174 |
| 36 | 2105.99 | 2429.80 | 5054 |
| 38 | 1929.33 | 2469.10 | 4888 |
| 40 | 1753.30 | 2509.80 | 4675 |

```
********************************************************************
************** THREE ELEMENT TORQUE CONVERTER PROGRAM, TC-4G   ****************
*******************************************************************
```

FILE CODE: TC-4G   REVISION 5/31/1990
NOTE: THIS PROGRAM IS PROPRIETARY DATA OF W. E. RODLER AND IS NOT TO BE USED OR
      COPIED WITHOUT HIS EXPRESS WRITTEN PERMISSION
```
======================================================================
```

DATA INPUT:

RUN DATE:900912	IMPELLER R1P---: 3.383	IMPELLER R2P --: 5
IMPELLER A1P -: 60	TURBINE A1T ---: 45	REACTOR A1R ---: 60
IMPELLER A2P -: 50	TURBINE A2T ---: 25	REACTOR A2R ---: 25
SECTION H ----: .6875	SIGMA ---------: .15	MIN. S. R. ----: 0
DESIGN RPM----: 1750	INCREMENTS ----: .05	RUN NUMBER ----: 900912

```
======================================================================
```
RESULTS:

SPEED RATIO=	TORQUE RATIO=	EFFICIENCY=	CAPACITY K=	FLOW Vn=
0.0000	3.8298	0.0000	238.3513	0.3016
0.0500	3.5643	17.8213	235.2564	0.2949
0.1000	3.3143	33.1430	232.3920	0.2877
0.1500	3.0792	46.1880	229.7743	0.2803
0.2000	2.8582	57.1643	227.4208	0.2724
0.2500	2.6506	66.2640	225.3514	0.2641
0.3000	2.4555	73.6636	223.5898	0.2555
0.3500	2.2721	79.5240	222.1654	0.2463
0.4000	2.0998	83.9909	221.1154	0.2367
0.4500	1.9377	87.1955	220.4884	0.2265
0.5000	1.7851	89.2550	220.3494	0.2157
0.5500	1.6413	90.2728	220.7877	0.2043
0.6000	1.5056	90.3386	221.9295	0.1922
0.6500	1.3774	89.5280	223.9595	0.1792
0.7000	1.2557	87.9007	227.1612	0.1652
0.7500	1.1400	85.4972	231.9967	0.1500
0.8000	1.0291	82.3306	239.2840	0.1332
0.8250	0.9752	80.4536	244.2999	0.1240
0.8500	0.9220	78.3677	250.6597	0.1142
0.8750	0.8692	76.0532	258.9280	0.1037
0.9000	0.8164	73.4753	270.1062	0.0920
0.9250	0.7629	70.5700	286.1802	0.0790
0.9500	0.7074	67.2053	311.9668	0.0638

```
======================================================================
```

TYPICAL TORQUE CONVERTER PERFORMANCE

X Data	EFFICIENCY, %	TORQUE RATIO X 10
0	0	38.30
0.05	17.82	35.64
0.10	33.14	33.14
0.15	46.19	30.79
0.20	57.16	28.58
0.25	66.27	26.51
0.30	73.66	24.56
0.35	79.52	22.72
0.40	83.99	21
0.45	87.20	19.38
0.50	89.26	17.85
0.55	90.27	16.41
0.60	90.34	15.06
0.65	89.52	13.77
0.70	87.90	12.55
0.75	85.50	11.40
0.80	82.33	10.29
0.85	80.45	9.75

5. TO ASSURE THE MECHANICAL CONCEPT COULD ADAPT TO THE HYDRODYNAMIC OPTIMIZATION, RUN IM 10315 B.SS WAS MADE. THIS ANALYSIS HAS BEEN PROGRAMMED ON A SPREAD SHEET THAT PERMITS A QUICK STUDY OF THE EFFECTS OF INLET AND DISCHARGE AREAS, FACE ANGLE CHANGES, MERIDIAN RADIUS CHANGES, ETC. WHILE THIS HAS NOT BEEN FULLY OPTIMIZED, THE BLADE ANGLES AT INLET AND DISCHARGE, AND THE PROGRESSION BETWEEN, CONFIRM THAT RESULTS WILL FALL IN A FAVORABLE DESIGN RANGE AND WILL BE EASILY PRODUCED. SEE PAGE 12

6. THE GEARING SIZE WAS DETERMINED AS SHOWN ON THE FOLLOWING PAGES 12 – 16. THE EFFORT STARTED WITH A REVIEW OF THE PREVIOUS WESTINGHOUSE DESIGN. THEY APPEAR TO BE USING A 12 P_d SET WITH A 15 TOOTH SUN, 39 TOOTH PLANETS AND A 93 TOOTH RING GEAR. FACE WIDTHS APPEAR TO BE ABOUT 1.5 FOR THE SUN AND 1.38 FOR THE PLANETS. FURTHER CHECK OF ASSEMBLY FEASIBILITY + TIP CLEARANCE ALSO WERE CHECKED AND FOUND OK.

7. GEAR LOADS WERE CHECKED FOR THE REFLEX JET USING AN EXISTING GEAR LOAD ANALYSIS PROGRAM. IF 15:39:93 TOOTH NUMBERS ARE USED, THE SETS SHOWN ON RUN GEARLO21 AND GEARLO15 LOOK GOOD. THE FORMER USES A 10 P_d AND A 1.1" FACE VS 12 P_d AND A 1.5" FACE FOR THE LATTER. IF SPACE ALLOWS, THE 10 P_d IS THE PREFERRED DESIGN. EITHER WOULD BE SATISFACTORY. THEIR STRESSES WERE BELOW THE WESTINGHOUSE DESIGN AND BELOW STRESS USED BY SUNDSTRAND IN THEIR HIGH SPEED GEAR CASES

IMPELLER CROSS SECTION FOR RUN #PX10315B, 1750 RPM

RUN #: IM10315B.SS   DATE: 90/11/20 BY:W.E. RODLER   FOR:

```
******* ****************************************************************************
        FROM RUNS#: 901031.5 OF 90/10/31 AND 901031.5B OF 90/11/20
        DATA INPUT:
                        RPM.....................:        1,750      MERIDIAN RADIUS OPTIMIZATION:
                        FLOW, GPM...............:       21,132.00
                        INLET AREA, IN-SQ.......:         183.16             EST RAD.....:   211.5300
                        INLET FACE ANGLE, DEG...:           3.00             H C/L 1.....:   217.2101
                        MERIDIONAL DIAMETER, IN.:          11.94             H C/L 2.....:   217.2101
                        DISCHARGE Vt = S2.......:          31.5100           ERROR, IN...:     0.0000
                        DISCHARGE AREA, IN-SQ...:         165.10
                        DISC. FACE ANGLE, DEG...:           5.00      AREA CHG/STA.......:     1.8060
                        MERIDIONAL DIAMETER, OUT.:         12.97      FACE ANGLE/STA.....:     0.2000
******* ****************************************************************************
```

STATION	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
AREA	183.16	181.35	179.55	177.74	175.94	174.13	172.32	170.52	168.71	166.91	165.10
ANGLE	3.00	3.20	3.40	3.60	3.80	4.00	4.20	4.40	4.60	4.80	5.00
OFFSETS											
Xm	11.0706	11.8079	12.5451	13.2821	14.0189	14.7556	15.4921	16.2284	16.9645	17.7004	18.4361
YM	5.9700	6.0099	6.0524	6.0975	6.1452	6.1954	6.2482	6.3035	6.3615	6.4220	6.4850
Yi	2.5554	2.7020	2.8472	2.9911	3.1342	3.2767	3.4186	3.5603	3.7018	3.8433	3.9849
Yo	8.0468	8.0584	8.0720	8.0878	8.1057	8.1258	8.1481	8.1727	8.1996	8.2288	8.2603
Xi	11.2496	11.9929	12.7355	13.4775	14.2189	14.9597	15.6999	16.4395	17.1785	17.9169	18.6548
Xo	10.9618	11.6934	12.4251	13.1569	13.8887	14.6206	15.3526	16.0845	16.8166	17.5487	18.2807
Vm(fps)	37.02	37.38	37.76	38.14	38.54	38.94	39.34	39.76	40.19	40.62	41.07
"E"	0.0000	0.0400	0.1550	0.2700	0.3850	0.50000	0.6150	0.7300	0.8450	0.9600	1.0000
Um	91.1716	91.7814	92.4305	93.1189	93.8466	94.6135	95.4197	96.2652	97.1499	98.0739	99.0371
DiSi	0.0000	8.1737	31.6733	55.1728	78.6723	102.1718	125.6713	149.1709	172.6704	196.1699	204.3436
Si	0.0000	1.3600	5.2331	9.0484	12.8023	16.4916	20.1133	23.6646	27.1432	30.5467	31.5100
Bm	22.0973	22.4626	23.4158	24.4847	25.4387	26.4914	27.5847	28.7077	29.8571	31.0289	31.3050
Bi	43.4867	42.6020	42.6317	42.7662	42.9927	43.2997	43.6774	44.1167	44.6093	45.1474	44.7027
Bo	16.7632	17.1371	17.9887	18.8841	19.8234	20.8064	21.8322	22.8994	24.0057	25.1484	25.5214

PLANETARY DESIGN

1. THIS UNIT WILL BE ARRANGED LIKE TYPICAL AUTOMOTIVE AXLE END PLANETARY REF: BOSCH AUTOMOTIVE HANDBOOK, 2ND ED, Pg 472

    A. ARRANGEMENT USES SUN IN & CARRIER OUT

    B. RATIO:

$$i = 1 + Z_B / Z_A \qquad \begin{matrix} Z_A = N_S \\ Z_B = N_R \end{matrix}$$

    C. IS GOAL IS $i = 7$, THEN:

$$7 = 1 + Z_B / Z_A$$
$$Z_B = 6 Z_A$$
$$\text{OR} \quad N_R = 6 N_S$$

$$\text{AND} \quad N_R = N_S + 2 N_P$$
$$\therefore \quad 6 N_S = N_S + 2 N_P$$
$$5 N_S = 2 N_P$$
$$N_P = 2.5 * N_S$$

2. FOR 8 D_P WITH $\cong$ 15T N_S :   @ 400 HP

	TOOTH #		
N_S	15	14	16
N_P	37.5 ← NG	35	40
N_R	90	84	96
S_B		91,149	83,725
S_E		302,584 ←	287,553
ASSEMBLY (REQUIRES INTEGER)		65.33	74.66

3 SCALED FROM WESTINGHOUSE ILLUSTRATIONS

    FLANGE DIA = 14 3/4

    SUN = $\overset{1.25}{\cancel{2.6}} D_P$

    R_{NION} = 3.25 D_P $\Big\}$ IS 12 P_d $\begin{cases} N_S = 15 \\ N_P = 39 \\ N_S = 93 \end{cases}$

    R_{ING} = $7\frac{3}{4} D_P$

    FACE = 1.375

Planetary Design

4 Westinghouse Ratio:

$$i = 1 + 93/15 = 7.20$$

5. Westinghouse Approximate Gear Sizes $(12 D_p)$

$$W_F$$

D_p Sun $= 1.25$ 1.50

D_p Planet $= 3.25$ 1.38

D_p Ring $= 7.75$ 1.38

6. Assembly Check

$$2 * (N_s + N_R)/n = \text{Integer}$$

$$2 * (15 + 93)/3 = 72 \leftarrow OK$$

7. Tip Clearance Check:

$$K. \text{ Max} = (2 N_s - 4)/\left[N_s \left(1 - \sin\left(\frac{190}{n}\right)\right)\right]$$

$$= 12.93 \leftarrow OK$$

8 Recheck On Computer
    A. Westinghouse Stress

    B. Revised HPM Stress @ Various Pitches, Same Tooth Numbers As Westinghouse

AAAV WATERJET GEAR SET LOADING CHART, GEARLO21

GEAR LOAD ANALYSIS PROGRAM   FILENAME: GEARLO21   11/21/90

DATA INPUT:

PINION "Np"	12	13	14	15	16	17	18	19	20	21
GEAR "Ng"	39	39	39	39	39	39	39	39	39	39
FACE WIDTH, INCHES	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100	1.100
DIAMETRAL PITCH	10	10	10	10	10	10	10	10	10	10
RPM	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
HORSEPOWER	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3
ACCURACY "e"	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
"k" FOR 20 DEG FD	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333
"C" FOR STEEL	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5

RESULTS:

RATIO = Ng/nP	3.2500	3.0000	2.7857	2.6000	2.4375	2.2941	2.1667	2.0526	1.9500	1.8571
PINION Dp, INCHES	1.2000	1.3000	1.4000	1.5000	1.6000	1.7000	1.8000	1.9000	2.0000	2.1000
GEAR Dp, INCHES	3.9000	3.9000	3.9000	3.9000	3.9000	3.9000	3.9000	3.9000	3.9000	3.9000
CENTER DIST. IN.	2.5500	2.6000	2.6500	2.7000	2.7500	2.8000	2.8500	2.9000	2.9500	3.0000
PINION OD, IN.	1.4000	1.5000	1.6000	1.7000	1.8000	1.9000	2.0000	2.1000	2.2000	2.3000
GEAR OD, IN.	4.1000	4.1000	4.1000	4.1000	4.1000	4.1000	4.1000	4.1000	4.1000	4.1000
PITCHLINE FT/MIN	3,298.7	3,573.6	3,848.4	4,123.3	4,398.2	4,673.1	4,948.0	5,222.9	5,497.8	5,772.7
PIN. TORQUE LB-FT	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7
STATIC TOOTH LBS.	1,333.5	1,230.9	1,143.0	1,066.8	1,000.1	941.3	889.0	842.2	800.1	762.0
DYNAMIC TOOTH LBS.	5,602.8	5,549.7	5,505.0	5,466.9	5,434.1	5,405.5	5,380.4	5,358.2	5,338.4	5,320.6
LEWIS FACTOR "Y"	0.245	0.264	0.276	0.289	0.295	0.302	0.308	0.314	0.320	0.326
BENDING PSI	207,897	191,105	181,324	171,970	167,461	162,719	158,808	155,131	151,659	148,373
FACTOR "K"	5,551	5,175	4,858	4,588	4,354	4,151	3,972	3,813	3,671	3,544
SURFACE PSI	425,780	411,104	398,328	387,089	377,114	368,194	360,161	352,886	346,262	340,201
MIN BACKING, IN.	0.155	0.161	0.167	0.173	0.179	0.184	0.190	0.195	0.200	0.205

AAAV WATERJET GEARLOAD, 12 PITCH, 1.5 FACE

GEAR LOAD ANALYSIS PROGRAM   FILENAME: GEARLO15   11/21/90

DATA INPUT:

PINION "Np"	12	13	14	15	16	17	18	19	20	21
GEAR "Ng"	39	39	39	39	39	39	39	39	39	39
FACE WIDTH, INCHES	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500	1.500
DIAMETRAL PITCH	12	12	12	12	12	12	12	12	12	12
RPM	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
HORSEPOWER	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3	133.3
ACCURACY "e"	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
"k" FOR 20 DEG FD	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333	0.0000333
"C" FOR STEEL	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5	499.5

RESULTS:

RATIO = Ng/nP	3.2500	3.0000	2.7857	2.6000	2.4375	2.2941	2.1667	2.0526	1.9500	1.8571
PINION Dp, INCHES	1.0000	1.0833	1.1667	1.2500	1.3333	1.4167	1.5000	1.5833	1.6667	1.7500
GEAR Dp, INCHES	3.2500	3.2500	3.2500	3.2500	3.2500	3.2500	3.2500	3.2500	3.2500	3.2500
CENTER DIST. IN.	2.1250	2.1667	2.2083	2.2500	2.2917	2.3333	2.3750	2.4167	2.4583	2.5000
PINION OD, IN.	1.1667	1.2500	1.3333	1.4167	1.5000	1.5833	1.6667	1.7500	1.8333	1.9167
GEAR OD, IN.	3.4167	3.4167	3.4167	3.4167	3.4167	3.4167	3.4167	3.4167	3.4167	3.4167
PITCHLINE FT/MIN	2,748.9	2,978.0	3,207.0	3,436.1	3,665.2	3,894.3	4,123.3	4,352.4	4,581.5	4,810.6
PIN. TORQUE LB-FT	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7
STATIC TOOTH LBS.	1,600.2	1,477.1	1,371.6	1,280.2	1,200.2	1,129.6	1,066.8	1,010.7	960.1	914.4
DYNAMIC TOOTH LBS.	6,247.7	6,204.2	6,169.4	6,141.2	6,118.1	6,099.0	6,083.1	6,069.7	6,058.3	6,048.6
LEWIS FACTOR "Y"	0.245	0.264	0.276	0.289	0.295	0.302	0.308	0.314	0.320	0.326
BENDING PSI	204,007	188,005	178,822	169,999	165,915	161,564	158,002	154,642	151,458	148,433
FACTOR "K"	5,447	5,091	4,791	4,535	4,314	4,121	3,951	3,801	3,666	3,545
SURFACE PSI	421,778	407,756	395,570	384,863	375,370	366,884	359,246	352,330	346,032	340,270
MIN BACKING, IN.	0.129	0.134	0.139	0.144	0.149	0.154	0.158	0.162	0.167	0.171

8. THE TWO HALVES OF THE CARRIER WILL BE BOLTED TOGETHER WITH SIX BOLTS TO ASSURE RIGIDITY AND TO CLAMP TUBULAR PLANET PINS. THE LAYOUT CONFIRMED THERE WAS AMPLE SPACE FOR 3 BOLTS THROUGH THE EQUALLY SPACED PLANET PINS PLUS THREE BOLTS ON ABOUT A 1.8 RADIUS, EQUALLY SPACED BETWEEN THE PLANET GEARS.

9. THE INLET ELBOW DIMENSIONS ARE DERIVED FROM THE PREVIOUS 7.34" WATERJET DESIGN. THE RUN 901214·1 ATTACHED AS PAGE 18 IS TYPICAL. THE PROPORTIONS CAN BE CHANGED, WITH DECREASED WIDTH IN THE FIRST SECTIONS PRODUCING INCREASED OUTER RADIUS (R_0) AND RESULTS IN INCREASED OVER ALL LENGTH. FURTHER DETAILED STUDY OF THE TRANSITION SECTIONS 9, 10 & 11 WILL BE NEEDED IN THE FINAL DESIGN TO CORRECT FOR EFFECTS OF ENDS OF SPLITTERS AND IMPELLER HUB.

10. THE COLLECTOR/NOZZLE DEVELOPMENT STARTS WITH AN ENTRANCE THAT IS PERPENDICULAR TO THE NORMAL FLOW FROM THE IMPELLER. A TYPICAL VALVE AT 1750 RPM FROM COMPUTER RUN PX10315B.SS IS 37.24°

11. THE AREA OF THE CAPTURE AREA IS FOUND BY

$$A_{in} = \pi / 4 * (16.5 \wedge 2 - 8 \wedge 2)$$

$$= 163.56 \ in^2$$

ELBOW DIMENSIONS, 14" WIDE INLET

ELBOW SECTION DEVELOPMENT PROGRAM								FILENAME:ELBOSE8E.SS		
								(Revision E)		
								RUN 901214.1		

SECT. NUMBER	SECT. AREA IN^2	TAPER IN/SEC	WIDTH IN.	CORNER RAD. IN.	HALF SECT. THICK	Ri IN.	R/D	R c/l IN.	Ro IN.	SECT. ANGLE DEG.
1	216.410	0.000	14.000	0.000	7.729	2.800	0.862	10.529	18.258	165.000
2	213.280	0.000	14.000	0.805	7.637	2.845	0.873	10.482	18.119	148.500
3	210.150	0.000	14.000	1.610	7.585	2.890	0.881	10.475	18.060	132.000
4	207.019	0.000	14.000	2.415	7.572	2.935	0.888	10.507	18.080	115.500
5	203.889	0.000	14.000	3.220	7.600	2.980	0.892	10.580	18.179	99.000
6	200.759	0.000	14.000	4.025	7.667	3.025	0.895	10.692	18.358	82.500
7	197.629	0.201	14.201	4.830	7.663	3.070	0.901	10.733	18.397	66.000
8	194.498	0.525	14.726	5.635	7.529	3.115	0.914	10.644	18.174	49.500
9	191.368	0.648	15.374	6.440	7.382	3.160	0.928	10.542	17.923	33.000
10	195.440	0.525	15.899	7.245	7.563	3.205	0.924	10.768	18.332	16.500
11	203.583	0.201	16.100	8.050	8.050	3.250	0.904	11.300	19.350	0.000

12. THE NORMAL VELOCITY IS DETERMINED FROM CONTINUITY OF FLOW:

$$V_n = 21132 \; GPM \times 231 \frac{IN^3}{GAL} \; / \; 60 \frac{SEC}{MIN} \; / \; 12 \frac{IN}{FT} \; / \; 163.56 \; IN^2$$

$$= 41.45 \; FT/SEC$$

13. THE VELOCITY IN THE PLANE PROJECTED PERPENDICULAR TO THE ABSOLUTE FLOW IS:

$$V_y = 41.45 / \cos 37.24$$

$$= 52.07 \; FT/SEC$$

14. THE NOZZLES (4) TAPER FROM $32.553 \; IN^2$ (FROM Pg 17, # 11 ABOVE, 163.56/4) TO 26.226, WHICH IS THE TOTAL NOZZLE AREA FROM THE OPTIMIZATION STUDY DIVIDED BY 4. A SAMPLE CALCULATION IS SHOWN IN RUN "NOZZLE 01", ATTACHED AS PAGE 20.

15. THE NOZZLES WERE DRAWN WITH A UNIFORM CURVATURE PER SECTION FROM THE 37.24° AT THE ENTRANCE TO 180° AT THE NOZZLE

16. THE EFFECT OF SPLAYING THE NOZZLES SLIGHTLY OUTWARD WAS INVESTIGATED AS SHOW IN RUN "NOZSPLAY:SS" SHOWN ON PAGE 21. THIS SHOWS THAT SMALL ANGLES PRODUCE SLIGHT LOSS OF THRUST AND SIGNIFICANT GAIN IN CLEARANCE. THIS WAS DONE WITH SUCCESS IN THE BOTTOM TWO NOZZLES OF THE 7.34" REFLEX JET. IT CAN BE DONE IN THIS APPLICATION TO MINIMIZE OVER ALL ENVELOPE SIZE

COLLECTOR/NOZZLE DEVELOPMENT

FILENAME: NOZZLE01

STA. #	AREA IN^2	CORNER RADIUS IN.	CORNER LOST AREA IN^2	VERT. HEIGHT IN.	WIDTH IN
1	32.553	0.000	0.000	4.250	7.660
2	31.920	0.289	0.072	4.403	7.266
3	31.288	0.578	0.287	4.556	6.931
4	30.655	0.867	0.645	4.709	6.647
5	30.022	1.156	1.147	4.862	6.411
6	29.390	1.445	1.792	5.014	6.218
7	28.757	1.734	2.581	5.167	6.065
8	28.124	2.023	3.513	5.320	5.947
9	27.491	2.312	4.588	5.473	5.861
10	26.859	2.601	5.807	5.626	5.806
11	26.226	2.890	7.170	5.779	5.779

EFFECT OF ANGLED NOZZLES   filename:NOZSPLAY:SS
                                            DEC. 13, 1990

ANGLE DEG.	THRUST LBS.	THRUST LOSS (%)	THRUST LOSS LBS.	SIDE THRUST (%)	SIDE THRUST LBS.	ADDED CLEARANCE AT: 1"	5"	10"	15"	20"
0	3,775	0.000	0	0.000	0	0.000	0.000	0.000	0.000	0.000
1	3,775	0.015	1	1.745	66	0.017	0.087	0.175	0.262	0.349
2	3,775	0.061	2	3.490	132	0.035	0.175	0.349	0.524	0.698
3	3,775	0.137	5	5.234	198	0.052	0.262	0.524	0.786	1.048
4	3,775	0.244	9	6.976	263	0.070	0.350	0.699	1.049	1.399
5	3,775	0.381	14	8.716	329	0.087	0.437	0.875	1.312	1.750
6	3,775	0.548	21	10.453	395	0.105	0.526	1.051	1.577	2.102
7	3,775	0.745	28	12.187	460	0.123	0.614	1.228	1.842	2.456
8	3,775	0.973	37	13.917	525	0.141	0.703	1.405	2.108	2.811
9	3,775	1.231	46	15.643	591	0.158	0.792	1.584	2.376	3.168
10	3,775	1.519	57	17.365	656	0.176	0.882	1.763	2.645	3.527
11	3,775	1.837	69	19.081	720	0.194	0.972	1.944	2.916	3.888
12	3,775	2.185	82	20.791	785	0.213	1.063	2.126	3.188	4.251
13	3,775	2.563	97	22.495	849	0.231	1.154	2.309	3.463	4.617
14	3,775	2.970	112	24.192	913	0.249	1.247	2.493	3.740	4.987
15	3,775	3.407	129	25.882	977	0.268	1.340	2.679	4.019	5.359
16	3,775	3.874	146	27.564	1,041	0.287	1.434	2.867	4.301	5.735